MECHANICAL PROPERTIES OF PLASTIC LAMINATES

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MECHANICAL PROPERTIES OF PLASTIC LAMINATES[1]

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Summary

This report presents the results of tension, compression, bending and shear tests of 14 laminated plastic materials. Tests of laminates were made after the specimens had been subjected to normal or to wet conditioning. The mechanical properties of the laminates, both dry and wet, are presented in the form of tables and by average stress-strain curves.

The results of the glass-fabric-polyester laminates are considered to be typical of laminates made with any polyester resin conforming to U. S. Air Force Specification 12049 and a specific glass fabric with finish 114. The mechanical properties of such laminates are substantially reduced after exposure to wet atmospheric conditions.

Introduction

This study was made to determine the mechanical properties parallel to the orthotropic axes of several plastic laminates, in tension, compression bending, and shear. The laminates tested include some that are now in considerable use for certain structural applications, especially aircraft, and others that have not been generally used.

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[1] This progress report is one of a series prepared and distributed by the Forest Products Laboratory under U. S. Navy, Bureau of Aeronautics No. NAer Order 00793 and U. S. Air Force No. USAF-PO-33-038 (50-1078-E). Results here reported are preliminary and may be revised as additional data become available. Original report published Feb. 1951.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

The primary purpose of the study was to obtain typical data on the mechanical properties, dry and wet, of laminates made of a glass fabric (with finish 114) and a polyester resin conforming with the requirements for Types I, II, and III of U. S. Air Force Specification 12049. Available data indicate that such a laminate, made from a specific glass fabric, will have about the same strength properties regardless of the type of polyester resin used. Further, the reduction in strength properties after wet conditioning is about the same for all such laminates. Thus, any polyester resin conforming to the above requirements may be used with a selected glass fabric, and the mechanical properties of the resultant laminate may be estimated from the corresponding values reported herein. This assumes, of course, that accepted and comparable fabrication techniques will be employed.

The typical data reported herein may be used also for other purpose. For example, the data may be used to estimate the strength at any angle to the warp direction[3] or to estimate the strength of cross laminates or of laminates made of a combination of fabrics.[4]

It should be noted that the strength properties are based on tests of specimens from flat panels. It is not to be expected that the values reported herein will be typical of structural parts molded to curved forms.

Results of tests of plastic laminates have been reported from many other sources, but they are too numerous to mention here. There is much variation between their reports in the types of resins and fabrics used, molding pressures and temperatures, test methods and conditions, and like factors. The laminates for the tests reported herein are considered to be reasonably representative of other laminates made by similar fabrication procedures.

Tests were made after normal or after wet conditioning. The wet test condition simulates service conditions that might exist after exposure to a tropical climate.

This investigation was made at the U. S. Forest Products Laboartory at Madison, Wis., between February 1949 and May 1950. It was made in cooperation with ANC-17 Panel on Plastics.

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[3] Forest Products Laboratory Reports No. 1803 (April 1949) and 1803-A (April 1950), "Directional Properties of Glass-Fabric-Base Plastic Laminates of Sizes That Do Not Buckle."

[4] Forest Products Laboratory Report No. 1821, "Mechanical Properties of Cross-Laminated and Composite Glass-Fabric-Base Plastic Laminates." February 1951.

Description of Material

Two 36- by 36-inch panels of each laminate supplied the specimens for these tests. The glass-fabric-base plastic laminates were made at the Forest Products Laboratory, and the cotton-fabric panels were purchased from the manufacturer of that type of laminate.

All panels were parallel laminated, including those of cotton fabric. The fabrication methods are indicated briefly in table 1, except that the procedures employed in making the cotton-fabric panels are not known.

The 11 laminates made with resin 2 were fabricated by essentially the same procedures. The lay-up of fabric and resin was made between cellophane-covered, 1/4-inch-thick aluminum cauls. After impregnation and lay-up, each panel was cured at a pressure of 14 pounds per square inch for 1 hour and 40 minutes in a press at a temperature gradually increasing from 220° to 250° F. Pressure was applied by means of an oil-filled steel bladder located on the bottom platen of the press.

The two panels made with resin 1 were made by methods slightly different from those just mentioned. The sheets were impregnated separately and rolled up to permit the resin to soak into the fabric. After about 16 hours the sheets were unrolled and laid up in panel form. The panels were cured between cellophane-covered aluminum cauls at a pressure of 14 pounds per square inch for 1 hour and 30 minutes in a press at a temperature of 220° F.

For the panels made with resin 9 the individual sheets were impregnated and hung up to dry overnight at room temperature. The panel was laid up the following day and pressed between cellophane-covered aluminum cauls at a pressure of 75 pounds per square inch for 1 hour and 30 minutes in a press at a temperature of 275° F.

In general, the two panels of each type of laminate were reasonably comparable in thickness, specific gravity, resin content, and Barcol hardness. The panels made of glass mat were, however, and exception. Although similar methods were used in fabrication, the panels are quite different due to the difference in resin content. No explanation is offered for this substantial variation.

After the pressing was completed, each panel was trimmed to size with a metal-cutting band saw. The panel was carefully measured and weighed, and the overall average resin content and specific gravity were calculated. Barcol hardness readings (fig. 1) were also made at various positions on each face of the panel. General information concerning each panel is included in table 1.

The cutting diagram for a typical laminated panel is shown in figure 2. The system of numbering clearly identifies each specimen. For example, specimen TA90-1-5-1 indicates:

T = Tension (C for compression, F for bending, and V for shear)
A = Type of laminate. In this case, glass 112-114, resin 2
90 = Angle of loading to direction of warp of laminations
1 = Project number
5 = Panel number
1 = Specimen number. Odd numbers tested dry; even numbers tested wet.

The tension, compression, and bending specimens were cut from glass-fabric panels with a 1/8-inch emery wheel rotated at 1,770 revolutions per minute in the arbor of a variable-speed table saw. This method of cutting assured square and smooth edges. The loading edges of the wet compression specimens were, however, ground flat with a surface grinder before testing to eliminate any slight distortion that might have taken place during the wet conditioning. The cotton-fabric panels were cut with a high-speed-steel circular saw. All tensile specimens were finished to the desired shape and curvature by use of an emery wheel mounted on a shaper head.

Panel shear specimens were cut to shape with a metal-cutting band saw.

Testing

General

Tension, compression, and bending specimens were conditioned to what is herein referred to as a "dry" (normal) or "wet" condition. Dry specimens were those conditioned for at least 1 month at a temperature of 75° F. and a relative humidity of 50 percent. Wet specimens were also conditioned as above, weighed, and then conditioned for at least 2 months more at a temperature of 100° F. and a relative humidity of near 100 percent. The wet tension and bending specimens were reweighed just before test to obtain a value of "percentage weight increase."

Panel shear specimens were not conditioned as above. The method of test and type of conditioning is described under "Panel Shear Tests," which follows.

Dry and wet specimens were stored in their respective atmosphere until time for test. The specimens were then removed and tested as soon as practicable under ordinary room conditions.

Tension Tests

The tensile specimens used in these tests were 16 inches long and of the thickness of the laminate. The maximum sections at the ends were 1-1/2 inches wide and 2-7/8 inches long. The minimum section at the center was 0.8 inch wide and 2-1/2 inches long. The maximum and minimum sections were connected by circular arcs of 20-inch radius tangent to the minimum section. This type of specimen was selected because it has a long tapered section that greatly reduces the

stress concentration at the test section. Experience has shown that the failure is not appreciably influenced by restraint at the ends of the specimen and generally occurs at the minimum section of the specimen.

The specimens were tested in a mechanical testing machine equipped with Templin tension grips (fig. 3). Load was applied at a head speed of about 0.035 inch per minute, and load-deformation readings were taken to failure. The strains were measured parallel to the applied load across a 2-inch gage length with a pair of Marten's mirrors reading to 0.00001 inch. The specimens failed suddenly in tension when the maximum load was reached.

Compression

The compression specimens used in these tests were 1 inch wide, 4 inches long, and of the thickness of the laminate. The specimens were loaded on the 1-inch ends and restrained from buckling by means of the apparatus illustrated in figure 4, which is described elsewhere.[5]

The specimens were loaded by means of a testing machine employing a spherical head. Load was applied at a head speed of about 0.012 inch per minute, and load-deformation readings were taken at regular increments of load until failure. The strains were measured parallel to the applied load with gages mounted on opposite edges of the specimen. For the dry specimens, a pair of Marten's mirrors were used at a 2-inch gage length. In the tests of wet specimens, Tuckerman strain gages of 1-inch gage length were employed.

A slight modification of the above procedure was required for the specimens of cotton-fabric laminate. Because of its low modulus of elasticity, excessive deformation occurred that made it impossible to use the restraining apparatus at higher loadings. Each specimen was therefore loaded in the apparatus to a stress well beyond the proportional limit so that the elastic properties might be determined. The load was then removed, and a specimen, 1 inch wide and 3/4-inch high, was cut from the center of the original specimen. The small specimen was then carefully alined in the testing machine without lateral support and loaded to failure.

For all specimens, the failure occurred suddenly when the maximum load was reached. Although there were slight differences in the character of failure between different laminates, all failures (including dry and wet specimens) were of the same type. Failures were a combination of transverse shear failure and crushing of the fibers, sometimes followed by some delamination of the specimen. A typical type of failure is shown in figure 5.

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[5] A. S. T. M. Designation D805-47, "Methods of Testing Plywood, Veneer, and Other Wood-Base Materials." 1947.

Bending Tests

Bending specimens were tested flatwise in a mechanical testing machine. The specimens were about 1/2 inch wide, 6 inches long, and of the thickness of the laminate, and were tested over a span of 4 inches. The contact edges of the end supports were of 1/8-inch radius, and the center loading piece had a radius of 3/8 inch. The rate of head travel was about 0.078 inch per minute, corresponding to a unit rate of fiber strain of about 0.007 inch per inch of outer fiber length per minute. Load was applied at the center of the specimen, and the deflection was measured with a dial gage (reading to 0.001 inch) having its spindle in contact with the bottom of the specimen at the center (fig. 6). Simultaneous readings of load and deflection were taken until the specimen failed at the maximum load.

In general, the glass-fabric laminates appeared to fail by a combination of compression and tension in both the dry and the wet conditions. Failure on the compression side was usually due to shear (as in the compression specimens described previously) and might be called a compression-shear type of failure. In most cases, this compression-shear type of failure probably occurred first, with the tension failure following immediately. There were only two laminates that failed differently from this general type. The 143-114 laminate failed in compression-shear at 0°, but in tension at 90°, and the cotton-fabric laminate failed in tension at both 0° and 90°.

Panel Shear Tests

The panel shear specimens were cut somewhat to the shape of a formee cross, the outline of which is that of figure 7. The part of the specimen common to the four arms of the cross was 3 inches square. Four pairs of machine-steel plates (fig. 8) having the shape of the arms of the cross, excluding the 3-inch square at the center, were bonded to the arms, with one plate on each side of each arm. Each plate was alined to its mate, during the bonding process, by two pins. When bonding was completed, machine bolts were added and tightened so that the specimen would be clamped between two plates. An assembled specimen with rollers and roller pins in place is shown in figure 7.

The load was applied to the rollers through triangular steel pieces that directed the load along the edges of the 3-inch-square central section of the specimen. Thus a condition of approximately pure shear was obtained in this section. The apparatus is shown, set up ready for test, in figure 9.

Load was applied at a head speed of about 0.01 inch per minute. Load and compression strain readings were taken at regular intervals of load. Strain measurements were made on opposite faces with a 1-inch-gage-length Tuckerman strain gage reading to 0.00001 inch. (Note that figures 7 and 9 show metalectric strain gages attached to the specimen. This was an exploratory specimen; metalectric gages were not used in the tests reported herein.)

There was considerable variation in the type of failure due to the shear stresses. Some of the laminates failed in the plane of maximum tension some

failed in the plane of maximum compression, some failed in shear along the warp or fill direction, and others failed by a combination of tension or compression with shear. In the laminate reinforced with glass mat, the maximum shear stress could not be developed because of failure in the bond between the metal plates and the specimen.

The reference to dry and wet test conditions in shear differs from that described for tension, compression, and bending tests. For the dry shear tests, the specimens were conditioned at a temperature of 75° F. and a relative humidity of 50 percent for at least 1 month prior to test. The steel plates were bonded to the arms of the specimen in a hot press, at a temperature of about 320° F., for 2 hours at a pressure of 200 pounds per square inch. The panel was tested as soon as the specimen had cooled to room temperature. Under these conditions, the moisture content of the specimen was undoubtedly lower than that of the other types of specimens that had been subjected to normal conditioning. The specimens to be used for wet tests were cut to shape and then conditioned at a temperature of 80° F. and 97 percent relative humidity for at least 1 month. When ready to test, the steel plates were cemented to the arms of the specimen (in the 80° F., 97 percent relative humidity room) with a room-temperature-setting adhesive. The assembled specimen was taken from the conditioning room just before test and was then tested as described previously.

Presentation of Data

Table 1 indicates the fabrication methods used in making the various laminated panels and gives some general information on each cured panel.

Average values from tension, compression, and bending tests are given in tables 2, 3, and 4, respectively.

Table 5 presents the results of the individual shear tests, including some that had been wet conditioned.

The ratios of wet-to-dry properties for the laminates are given in table 6. At the bottom of the table are included the average ratios for the 10 laminates made of glass cloth and resin 2. (Values from items 1-12, 1-14, 1-15, and 1-19 are not included in these averages.)

A series of average stress-stain curves in tension, compression and shear, and average load-deflection curves in bending are shown in figures 10 through 23 for each laminate. From the origin to the proportional limit, the curves are made to represent the average properties given in tables 2 through 5. beyond the proportional limit, they represent average tendencies from the load-deformation data.

The relationship between tangent modulus and stress, in compression and shear, is shown in figures 24 through 37 for each laminate. These curves are plotted from the corresponding average stress-strain curves of figures 10 through 23.

Discussion of Results

General

The mechanical properties of the 14 laminates reported herein are presented in the form of both tables and curves. Thus the dry and wet values may be readily compared by either method. The results from the various types of tests will be discussed separately.

Incidental to obtaining the mechanical properties of the laminates some information was gathered on the dimensional and weight change due to wet conditioning. Tension and bending specimens were measured and weighed after dry conditioning before being subjected to the wet atmosphere. The speciemens were remeasured and reweighed just before test, and the linear measurements thus recorded were used for calculating the mechanical properties observed in test. Actually, the change in dimension due to wet conditioning was small for all laminates, averaging roughly 1 percent increase in thickness and less than 1/2 percent increase in width. Similarly, the percentage increase in weight was small. These values of weight change are given with the properties for tension and bending in tables 2 and 4 respectively.

The small absorption of moisture does, in general, appreciably lower the mechanical properties of the laminate. The series of curves included in this report are intended, in part, to help visualize the changes resulting from wet conditioning. Table 6, which gives the ratios of wet properties to the corresponding dry ones, is also a convenient method of comparison.

The results tabulated in table 6 show that the mechanical properties of the glass-fabric laminate made with the phenolic resin (resin 9) were affected much less by wet conditioning than those made with the polyester resins (resins 1 and 2). This was true in tension, compression, and bending tests, and it would probably also apply to shear. It is of interest to note, however, that the percentage weight increase due to wet conditioning was more than three times greater for the 181-114, (9) laminate than for 181-114, (2) laminate.

The 128-114 fabric used in item 1-13 was approximately the same as the 128-114 fabric used in item 1-3, but it was made by a different manufacturer. Dry and wet properties of these two laminates were reasonably comparable, but those of the laminate under item 1-13 were slightly lower. The manufacturer of this latter fabric has, however, since reportedly imporved his manufacturing techniques. It is expected that subsequent 128-114 fabric may be assumed to be the same as the 128-114 fabric tested under item 1-3.

The laminated panels reinforced with M-503 mat varied considerably in resin content and in other properties, although the same techniques were used in making each. In addition, another panel was manufactured, but it was culled because of its poor quality. It appears that improved techniques would be required to manufacture uniform flat panels of this type. Because of the variation of the two panels tested, the average values of each have been reported separately in both tables and curves.

Detailed discussion on each of the laminates is not included in this report because the information is presented in both tables and curves and is therefore readily available. It should be remembered that all panels for these tests were parallel laminated, including the one made of 143-114 fabric. Some dry tests of composite and cross-laminated glass-fabric laminates have been made in connection with this program, and these are reported in another publication.[4]

The average wet-to-dry ratios for the mechanical properties of 10 laminates made of glass fabric with resin 2 are given at the bottom of table 6. These values were averaged because each laminate was made from a glass fabric, a single resin, and by the same fabrication techniques, and the ratios of the wet-to-dry properties are reasonably comparable. The ratios from the other polyester laminate (item 1-14) are also comparable. The ratios of wet strength to dry strength, expressed as percentages, are roughly as follows: (1) tension (0° and 90°), 80 percent; (2) tension (45°), 65 percent; (3) compression (0° and 90°), 60 percent; and (4) bending (0° and 90°), 65 percent.

Tension

The significance of the dual straight lines that occur in many tensile stress-strain curves of laminates, and that result in initial and secondary values of modulus of elasticity and proportional limit, has been questioned for some time. A previous report on the effect of prestressing[6] indicates that once the material has been stressed beyond the initial proportional limit, the initial tensile properties are changed. If the material is stressed as high as the secondary proportional limit, these dual properties are no longer present. Thus, these data indicate that the dual values reported with tensile properties are probably not significant for ordinary structural applications of the material and might be replaced by a single value of modulus of elasticity and of proportional limit. The report suggests that, in the absence of additional data, the secondary values of modulus of elasticity and proportional limit might be reasonable values to use for most design purposes. The above comments are applicable to specimens that were tested in the dry condition.

A study of the dry and the wet tensile values included in this report minimizes further the significance of the dual values. While there may be about 15 or 20 percent difference between the initial and secondary moduli in the dry condition, the difference is usually well under 10 percent for specimens tested in the wet condition, and in some cases the dual values do not appear to exist. It would seem, therefore, that the wet secondary values of modulus of elasticity and proportional limit might also be reasonable values to use when designing for laminates to be used in the wet condition.

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[6] Forest Products Laboratory Report No. 1811, "Effect of Prestressing in Tension or Compression on the Mechanical Properties of Two Glass-Fabric-Base Plastic Laminates." September 1950.

It may be noted that the above comments are applicable particularly to glass-fabric polyester laminates. In the 181-114, (9) laminate, the tensile properties were about the same in both the dry and the wet conditions.

Wet conditioning caused a greater percentage reduction in the tensile properties at 45° than at the 0° or 90° angles of loading.

Compression

The results of compression tests, table 3, show that dual values were not observed in compression, with the exception of the M-503 laminate in the dry condition. When tested in the wet condition, the dual characteristics of this laminate likewise did not appear to be present. Occasionally, a specimen of some other laminate would seem to have dual-line tendencies, but these were indefinite. Where these tendencies did appear to exist, the test was in the dry condition and the difference in the slopes of the lines was small. Therefore, for practical consideration, a single value of modulus of elasticity and of proportional limit seems applicable to the fabric-reinforced laminates.

Examination of the average stress-strain curves in compression shows that most curves do not deviate greatly from initial straight portion to failure. Thus the value of 0.2 percent offset stress is usually equal to the ultimate stress.

Bending

The bending tests were made as described previously under "Testing," and the results are given in table 4.

Panel Shear Tests

The difficulty of making an accurate shear test has long been recognized. Although approximately pure shear stresses may be applied to a panel when first loaded, subsequent deformation or local failures cause a complication distribution of stress. However, the type of apparatus used for these tests has proven reasonably satisfactory for other shear tests of glass-fabric laminates[2,3]. The correlation between experimental and theoretical shear values is included in the reports of these previous tests.

An examination of the results of individual shear tests shows that the agreement of properties between the two or more tests of a laminate is generally good (table 5). Values of ultimate stress are especially in good agreement. In the three instances where these values are not given, the ultimate stress was not attained because failure occurred in the laminate between the metal plates.

The theoretical shear stress has been calculated for each laminate from the corresponding results of tension tests at 0°, 45°, and 90°. The equation used in making these calculations is taken from a previous report.[2]

$$\frac{1}{F_x^2} = \frac{\cos^4\theta}{F_a^2} + \frac{\sin^4\theta}{F_b^2} + \frac{\sin^2\theta \quad \cos^2\theta}{F_{ab}^2} \tag{15}$$

where $\theta = 45°$

$F_x = F_{45}$ = maximum tensile stress at 45°

F_a = maximum tensile stress at 0°

F_b = maximum tensile stress at 90°

A comparison of observed and theoretical values of ultimate stress in the dry condition (columns 7 and 9 of table 5) shows that values are in reasonable agreement, but that the observed values are generally higher. This is as expected because, as has been mentioned previously, the panel shear test specimen undoubtedly had a lower moisture content than the related tensile specimens and the shear strength would thus be expected to be higher. From these dry tests it would appear that the shear strength could be calculated from the tension tests, as has been mentioned in previous reports on glass-fabric laminates.

A comparison between observed and theoretical values from tests in the wet condition (columns 13 and 15 of table 5) indicates poor agreement between these values. The theoretical shear strength (based on tensile tests) is considerably lower than the observed shear strength. This may be due, in part, to differences of temperature and of moisture absorption that might result from the conditioning methods. Tensile specimens were conditioned at 100° F. and near 100 percent relative humidity, but the closed containers used for this conditioning were not adaptable to the storage and gluing required for the panel shear specimens. The shear specimens were, therefore, placed in the conditioning room maintained at 80° F. and 97 percent relative humidity, which was the only suitable room available with atmospheric conditions near those desired. Results of bending tests show that the bending properties of specimens conditioned at 100° F. are slightly lower than those of specimens conditioned at 75° F., even though the relative humidity is about the same.[7] A similar effect might be expected in shear. Another factor that might account for a difference in shear strength is that the width of the shear specimen in the plane of the panel is 3 inches, while in the tension specimen it is only 0.8 inch. It might be expected that vapor or water would penetrate through the laminate more readily along the fibers than through the thickness of the laminate, although no such comparative tests have been made at this Laboratory. Thus it would appear that moisture absorption and consequent strength reduction would be greater for tensile specimens because of the combination of higher temperature and shorter distance for moisture penetration. It is believed that since

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[7] Forest Products Laboratory Report No. 1819, "Effect of Moisture Absorption on Flexural Properties of Glass-Fabric-Polyester Laminate." October 1950.

the laminated materials remain orthotropic even when in the wet condition, the theoretical analysis should apply. Therefore the theoretical values (based on wet tension tests) are probably more nearly representative of the wet shear strength at 100° F. than the panel-shear-test values themselves. Wet shear strength would be expected to be roughly 60 percent of the dry strength for glass-fabric-polyester laminates.

The equation previously given is not applicable to the laminated panels made of M-503 mat, since this material might be considered isotropic in the plane of the laminate.

Conclusions

The mechanical properties of the 14 laminates tested for this study may be seen by reference to the tables and curves presented in this report. Results for the glass-fabric-polyester laminates are considered to be typical of laminates made with specific glass fabrics with finish 114 and any polyester resin conforming to U. S. Air Force Specification 12049.

Wet conditioning, in general, substantially reduced the mechanical properties of glass-fabric-polyester laminates. Ratios of wet strength to dry strength, expressed as percentages, were roughly as follows: (1) tension (0° and 90°), 80 percent; (2) tension (45°), 65 percent; (3) compression (0° and 90°), 60 percent; and (4) bending (0° and 90°), 65 percent.

The dry mechanical properties of the single glass-fabric-phenolic laminate tested were generally a little less than those of the comparable polyester laminate. However, the properties of the phenolic laminate were only slightly decreased after wet conditioning, and were higher than those of the wet polyester laminate.

In tension, at 0° and 90° loading, the ratio of initial to secondary modulus of elasticity in the wet condition was usually considerably less than the same ratio in the dry condition. It appears that secondary values of modulus of elasticity and of proportional limit would probably be satisfactory for most design purposes. Actually, the secondary modulus from the wet tests is, on the average, only a few percent less than the corresponding modulus of elasticity from the dry tests.

There is reasonable agreement between observed and theoretical values of shear strength in the dry condition, but the agreement is not good in the wet condition. Actually, the theoretical wet values are expected to be near the true wet strength at 100° F., and, if used, would be conservative values.

APPENDIX 1

Description of Laminating Resins and Fabrics Used in Making Laminates

Resin 1.--A high-temperature-setting, high-viscosity, laminating resin of the polyester (diallyl phthalate-alkyd) type.

Resin 2.--A high-temperature-setting, low-viscosity, laminating resin of the polyester (styrene-alkyd) type.

Resin 9.--A high-temperature-setting laminating resin of the phenolic type.

Glass Fabric.--All glass fabric is of the weave listed in table 1, and of finish 114. Except for items 1-13 and 1-19, the fabric and mat were purchased from Manufacturer A. The 128 fabric for item 1-13 was purchased from Manufacturer B.

Cotton Fabric.--The cotton-fabric-base phenolic panels were purchased from Manufacturer C. The laminate was reinforced with 8.15-ounce cotton fabric, and the resin content was about 50 percent by weight.

Table 1.--Fabrication methods used in making laminated panels and general information on cured panels

Item No.	Fabrication methods: Type of fabric[1]	Resin[1]	Number of plies	Pressure	Temperature	Time of cure	Average values from cured panel: Panel No.	Thickness	Specific gravity	Resin content	Barcol hardness
				P.s.i.	°F.	Min.		Inch		Percent	
1 - 1	Glass 112 - 114	2	84	14	220 - 250	100	5	0.250	1.71	43.5	69
							6	.250	1.70	43.4	69
1 - 2	Glass 116 - 114	2	70	14	220 - 250	100	60	.243	1.83	34.0	69
							61	.249	1.82	35.1	68
1 - 3	Glass 128 - 114	2	36	14	220 - 250	100	12	.245	1.80	35.0	67
							13	.244	1.81	34.8	67
1 - 4	Glass 162 - 114	2	17	14	220 - 250	100	52	.252	1.76	37.7	62
							53	.254	1.76	38.2	62
1 - 6	Glass 143 - 114	2	26	14	220 - 250	100	7	.247	1.85	32.2	69
							8	.247	1.85	32.1	70
1 - 7	Glass 120 - 114	2	61	14	220 - 250	100	14	.256	1.72	41.8	71
							15	.250	1.74	40.9	71
1 - 8	Glass 181 - 114	2	23	14	220 - 250	100	16	.249	1.77	37.8	69
							17	.244	1.77	36.8	70
1 - 9	Glass 182 - 114	2	18	14	220 - 250	100	63	.245	1.82	33.4	68
							64	.245	1.84	33.8	66
1 - 11	Glass 184 - 114	2	9	14	220 - 250	100	55	.238	1.87	30.1	67
							56	.238	1.87	29.9	67
1 - 12	Glass mat M-503	2	13	14	220 - 250	100	18	.268	1.69	32.6	62
							68	.338	1.61	43.9	55
1 - 13	Glass[2] 128 - 114	2	36	14	220 - 250	100	27	.264	1.78	40.3	71
							28	.262	1.79	40.0	69
1 - 14	Glass 181 - 114	1	23	14	220	90	19	.263	1.81	42.8	74
							20	.266	1.80	42.8	73
							[3]71	.248	1.85	40.2	68
1 - 15	Glass 181 - 114	9	23	75	275	90	65	.231	1.83	35.3	61
							66	.236	1.81	35.8	58
1 - 19	Cotton [4]	Phenolic	16	....	....	....	50	.260	1.36	....	47
							51	.254	1.36	....	46

[1]Key to fabrics and resins in appendix.

[2]Fabric for this laminate made by different manufacturer than fabric used in item 1 - 3.

[3]Special panel, 12 by 12 inches, for shear test only.

[4]Cotton-fabric-base phenolic, postforming stock. Panels furnished by commercial manufacturer.

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Table 2.--Results of tension tests of laminated plastic specimens after normal or wet conditioning. Six specimens tested in each direction for each laminate

Item No.	Panel No.	Laminate	Condition[1]	Loaded parallel (0°) to warp of laminations: Modulus of elasticity: Initial	Modulus of elasticity: Secondary	Proportional limit: Initial	Proportional limit: Secondary	Ultimate stress	Increase in weight[2]	Loaded perpendicular (90°) to warp of laminations: Modulus of elasticity: Initial	Modulus of elasticity: Secondary	Proportional limit: Initial	Proportional limit: Secondary	Ultimate stress	Increase in weight[2]	Loaded at 45° to warp of laminations: Modulus of elasticity	Proportional limit	Ultimate stress	Increase in weight[2]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
				1,000 p.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	Percent	1,000 p.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	Percent	1,000 p.s.i.	P.s.i.	P.s.i.	Percent
1 - 1	5, 6	112 - 114, (2)	D	2,690	2,390	11,780	29,480	42,700		2,640	2,240	9,800	27,050	38,660		1,540	3,760	20,560	
			W		2,320		23,720	31,900	1.36		1,950		14,900	30,190	1.48	790	3,200	12,970	1.42
1 - 2	60, 61	116 - 114, (2)	D	3,570	3,010	6,820	29,300	47,010		2,950	2,640	8,200	33,110	46,680		1,830	3,740	22,790	
			W	2,810	2,700	5,960	21,470	36,850	.73	2,580	2,480	5,970	19,340	33,180	.62	1,040	2,320	13,560	.71
1 - 3	12, 13	128 - 114, (2)	D	3,590	3,140	6,660	29,100	51,610		2,760	2,160	6,450	24,460	39,640		1,790	3,940	23,360	
			W	3,150	3,050	8,240	19,590	39,380	1.00	2,370	2,180	4,890	16,660	30,220	1.07	1,020	2,160	14,030	1.15
1 - 4	52, 53	162 - 114, (2)	D	3,160	2,840	6,690	22,580	45,160		2,220	1,730	4,510	16,700	29,710		1,520	4,120	17,180	
			W		2,500		7,660	32,520	.78		1,710		6,500	23,480	.59	1,050	2,380	11,680	.55
1 - 6	7, 8	143 - 114, (2)	D		5,690		61,680	89,850		1,690	440	2,650	8,460	10,730		1,660	3,890	14,000	
			W		4,990		55,790	73,200	.97	1,020	440	2,130	6,290	9,120	1.18	800	3,240	8,860	1.15
1 - 7	14, 15	120 - 114, (2)	D	3,060	2,720	12,380	37,510	49,780		2,970	2,560	6,580	26,370	46,800		1,870	3,720	23,430	
			W		2,600		21,700	41,600	1.18		2,180		17,910	38,470	1.24	790	2,550	14,000	1.27
1 - 8	16, 17	181 - 114, (2)	D	2,950	2,626	7,020	29,270	49,100		2,800	2,420	6,710	25,120	45,380		1,770	3,700	22,930	
			W	2,760	2,660	5,030	24,620	40,940	.78	2,770	2,560	7,040	21,960	38,790	.82	1,220	2,640	15,150	.74
1 - 9	63, 64	182 - 114, (2)	D	3,210	2,800	6,250	28,840	51,230		3,050	2,600	6,000	26,720	50,160		1,830	3,600	21,790	
			W	3,080	2,920	6,560	24,590	45,200	.67	2,760	2,570	5,980	22,550	41,510	.61	1,240	2,640	13,920	.74
1 - 11	55, 56	184 - 114, (2)	D	3,510	3,110	7,260	29,550	53,720		2,950	2,460	5,640	24,690	45,020		1,930	3,730	18,940	
			W	2,970	2,550	7,050	22,000	45,980	.73	2,600	2,200	6,240	19,250	40,080	.68	1,190	2,530	12,730	.76
1 - 12	18	M-503, (2)	D	1,990	1,550	4,870	11,980	28,540		2,090	1,680	5,960	17,600	28,420		[3]i 2,050 s 1,580	[3]i 4,310 s13,730	27,280	
			W		1,450		10,590	22,920	.56		1,570		14,290	23,340	.80	1,540	11,220	21,910	.86
	68	M-503, (2)	D	1,860	1,580	3,790	9,860	24,500		1,930	1,580	4,230	11,700	25,180		i 2,180 s 1,660	i 3,960 s12,590	26,260	
			W		1,300		8,980	18,510	.68		1,420		8,020	19,190	.61	1,330	10,440	19,700	.93
1 - 13	27, 28	[4]128 - 114, (2)	D	3,100	2,750	6,670	23,990	36,840		2,650	2,080	4,940	21,350	33,940		1,580	3,310	19,630	
			W	2,810	2,660	6,020	16,030	28,060	.83	2,380	2,220	5,360	15,780	28,290	.95	980	2,580	13,120	.97
1 - 14	19, 20	181 - 114, (1)	D	2,690	2,410	5,610	25,210	43,450		2,530	2,280	5,630	22,520	41,970		1,300	3,630	20,150	
			W	2,590	2,420	5,770	22,830	39,370	1.93	2,500	2,320	5,170	18,400	35,920	1.96	830	2,660	13,340	1.99
1 - 15	65, 66	181 - 114, (9)	D	3,080	2,640	6,940	27,570	45,450		2,830	2,520	6,420	25,330	43,520		1,770	4,720	21,000	
			W	2,980	2,580	8,200	28,700	43,850	2.99	2,800	2,450	7,420	25,920	42,530	2.64	1,680	4,960	17,220	2.15
1 - 19	50, 51	Cotton fabric	D		1,050		4,060	10,520			1,030		4,220	10,430		940	3,860	8,410	
			W		810		2,930	9,530	2.82		740		2,610	9,940	2.37	680	2,240	7,810	2.92

[1] D = Dry, conditioned at 75° F. and 50 percent relative humidity.
W = Wet, conditioned at 100° F. and near 100 percent relative humidity.

[2] Increase in weight = $\frac{\text{weight after wet conditioning - weight after normal conditioning}}{\text{weight after normal conditioning}} \times 100$

[3] i = initial value; s = secondary value

[4] Fabric for this laminate made by different manufacturer than fabric used in item 1 - 3

Z M 85623 F

Table 3.--Results of compression tests of laminated plastic specimens after normal or wet conditioning. Six specimens tested in each direction for each laminate

Item No.	Panel No.	Laminate	Condition[1]	Loaded parallel (0°) to warp of laminations: Thickness	Modulus of elasticity	Proportional limit stress	0.2 percent offset stress	Ultimate stress	Loaded perpendicular (90°) to warp of laminations: Thickness	Modulus of elasticity	Proportional limit stress	0.2 percent offset stress	Ultimate stress
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
				Inch	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	Inch	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.
1 - 1	5, 6	112 - 114, (2)	D	0.248	2,820	23,250	36,840	36,840	0.254	2,630	21,620	32,900	32,900
			W	.252	2,470	20,100	28,360	28,360	.256	2,340	17,420	21,860	21,860
1 - 2	60, 61	116 - 114, (2)	D	.247	3,200	17,960	28,900	28,900	.249	3,120	17,630	26,460	26,460
			W	.248	2,820	11,930	16,660	16,660	.253	2,560	11,330	13,960	13,960
1 - 3	12, 13	128 - 114, (2)	D	.241	3,690	15,530	25,980	25,980	.251	2,830	15,820	25,810	25,810
			W	.245	2,890	11,480	15,450	15,450	.252	2,230	10,040	15,080	15,080
1 - 4	52, 53	162 - 114, (2)	D	.250	2,810	12,530	18,680	18,680	.258	2,190	16,210	21,240	21,240
			W	.252	2,580	5,460	10,860	10,910	.261	1,870	6,620	12,400	12,400
1 - 6	7, 8	143 - 114, (2)	D	.245	5,180	36,680	51,980	51,980	.253	1,590	11,450	20,660	21,920
			W	.246	4,870	28,360	32,990	32,990	.251	980	10,640	14,130	14,130
1 - 7	14, 15	120 - 114, (2)	D	.254	2,960	23,170	35,220	35,220	.253	2,880	18,470	30,600	30,600
			W	.256	2,600	19,260	24,540	24,540	.252	2,390	16,370	20,440	20,440
1 - 8	16, 17	181 - 114, (2)	D	.242	3,300	22,530	34,510	34,510	.249	3,170	22,780	36,350	36,350
			W	.243	2,900	18,550	23,940	23,940	.249	2,690	17,220	22,340	22,340
1 - 9	63, 64	182 - 114, (2)	D	.245	3,140	25,120	34,270	34,270	.248	3,000	21,880	27,720	27,720
			W	.247	2,920	16,880	21,870	21,870	.248	2,760	15,020	19,670	19,670
1 - 11	55, 56	184 - 114, (2)	D	.237	3,330	24,600	28,400	28,400	.242	2,960	20,150	25,670	25,670
			W	.240	3,010	12,400	17,330	17,330	.243	2,630	10,980	16,450	16,450
1 - 12	18	M-503, (2)	D		[2]i 2,290	[2]i 10,270				[2]i 2,280	[2]i 14,190		
				.259	s 1,900	s 18,960	24,200	25,920	.272	s 2,000	s 20,770	25,970	25,970
			W	.263	1,540	6,410	11,340	11,340	.274	1,610	6,910	12,250	12,250
	68	M-503, (2)	D		[2]i 2,210	[2]i 6,440				[2]i 2,160	[2]i 6,520		
				.348	s 1,860	s 14,050	21,070	21,660	.347	s 1,860	s 13,830	22,010	23,510
			W	.349	1,370	6,290	9,370	9,370	.348	1,380	6,380	9,300	9,300
1 - 13	27, 28	[3]128 - 114, (2)	D	.261	3,470	15,680	27,690	27,690	.268	2,980	15,180	28,550	28,550
			W	.264	2,700	9,680	13,780	13,780	.268	2,290	9,290	14,680	14,680
1 - 14	19, 20	181 - 114, (1)	D	.272	2,650	26,140	33,070	33,070	.262	2,890	19,950	36,320	36,320
			W	.278	2,530	17,840	24,240	24,240	.269	2,440	17,670	23,000	23,000
1 - 15	65, 66	181 - 114, (9)	D	.236	3,040	24,220	32,560	32,560	.232	3,110	27,320	29,800	29,800
			W	.238	3,200	24,220	31,650	31,650	.237	3,060	20,720	28,510	28,510
1 - 19	50, 51	Cotton fabric	D	.252	940	3,200	6,830	23,040	.253	930	3,260	6,970	23,270
			W	.261	780	1,480	4,900	15,650	.265	770	1,390	4,580	14,790

[1] D = Dry, conditioned at 75° F. and 50 percent relative humidity.

W = Wet, conditioned at 100° F. and near 100 percent relative humidity.

[2] i = initial value; s = secondary value.

[3] Fabric for this laminate made by different manufacturer than fabric used in item 1 - 3.

Z M 85624 F

Table 4.--Results of bending tests of laminated plastic specimens after normal or wet conditioning. Specimens were 1/2 inch wide and center-loaded over a 4-inch span. Six specimens tested in each direction for each laminate

Item No.	Panel No.	Laminate	Condition[1]	Span parallel (0°) to warp of laminations: Depth	Modulus of elasticity	Proportional limit stress	0.2 percent offset yield stress	Modulus of rupture	Increase in weight[2]	Span perpendicular (90°) to warp of laminations: Depth	Modulus of elasticity	Proportional limit stress	0.2 percent offset yield stress	Modulus of rupture	Increase in weight[2]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
				Inch	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	Percent	Inch	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	Percent
1 - 1	5,6	112 - 114, (2)	D	0.250	2,590	31,000	58,260	58,260	....	0.251	2,400	26,430	48,340	48,340	....
			W	.253	2,180	28,200	38,130	38,130	1.02	.252	2,010	23,020	29,960	29,960	0.92
1 - 2	60,61	116 - 114, (2)	D	.248	2,860	28,650	43,800	43,800	....	.248	2,690	26,280	38,570	38,810	....
			W	.249	2,590	20,040	27,160	27,260	.84	.249	2,380	16,610	24,300	24,300	.79
1 - 3	12,13	128 - 114, (2)	D	.237	3,180	26,080	46,410	46,950	....	.247	2,470	19,810	39,280	39,840	....
			W	.240	2,700	15,360	25,860	26,070	.70	.248	2,040	13,990	22,940	23,260	.65
1 - 4	52,53	162 - 114, (2)	D	.250	2,660	19,890	33,750	36,550	....	.253	1,920	15,300	28,450	32,470	....
			W	.252	2,240	14,970	22,010	23,850	.84	.254	1,620	14,760	20,700	23,470	.76
1 - 6	7,8	143 - 114, (2)	D	.247	4,750	83,300	93,540	93,540	....	.248	1,440	5,620	10,320	18,080	....
			W	.248	4,320	38,630	47,480	48,340	.87	.250	950	4,250	8,020	14,550	.86
1 - 7	14,15	120 - 114, (2)	D	.258	2,660	32,380	57,320	57,320	....	.250	2,580	24,890	45,320	45,320	....
			W	.259	2,230	27,510	35,150	35,150	.94	.252	2,120	21,660	27,430	27,650	.62
1 - 8	16,17	181 - 114, (2)	D	.252	2,810	34,200	54,410	55,340	....	.253	2,640	29,500	50,200	50,290	....
			W	.251	2,450	26,050	33,580	33,830	.95	.250	2,290	25,230	31,540	31,700	1.01
1 - 9	63,64	182 - 114, (2)	D	.251	2,790	39,480	50,280	50,280	....	.247	2,730	31,400	46,140	47,520	....
			W	.253	2,620	25,450	33,430	33,650	.78	.248	2,480	24,750	33,100	33,360	.78
1 - 11	55,56	184 - 114, (2)	D	.243	2,870	34,780	43,580	48,190	....	.242	2,550	27,670	42,380	43,980	....
			W	.242	2,850	21,470	30,590	32,230	1.11	.243	2,310	19,930	28,030	29,380	1.03
1 - 12	18	M-503, (2)	D	.243	2,020	13,040	28,430	36,370	....	.262	1,950	15,980	32,260	38,650	....
			W	.246	1,410	13,080	18,460	18,980	.82	.269	1,310	13,530	18,240	18,910	.77
	68	M-503, (2)	D	.364	1,710	19,120	32,860	33,200	....	.351	1,550	16,110	31,260	31,900	....
			W	.363	1,460	11,570	17,790	18,120	.86	.355	1,180	14,910	18,400	18,550	.74
1 - 13	27,28	[3]128 - 114, (2)	D	.259	3,030	27,440	43,520	43,520	....	.262	2,580	22,440	39,340	40,080	....
			W	.260	2,420	15,270	25,060	25,640	.84	.264	2,060	14,310	23,240	23,640	.85
1 - 14	19,20	181 - 114, (1)	D	.262	2,680	31,560	55,520	56,160	....	.260	2,550	33,680	52,770	53,320	....
			W	.265	2,290	30,480	35,120	35,120	1.64	.267	2,160	25,050	32,660	32,660	1.64
1 - 15	65,66	181 - 114, (9)	D	.235	2,640	37,420	51,190	51,190	....	.236	2,450	36,140	43,830	43,830	....
			W	.236	2,810	31,190	44,600	44,710	3.74	.235	2,700	29,440	39,350	39,350	3.36
1 - 19	50,51	Cotton fabric	D	.254	910	5,850	10,030	16,910	....	.256	960	6,380	10,590	18,680	....
			W	.258	710	4,920	8,060	15,380	3.65	.259	730	4,918	8,290	17,500	3.96

[1]D = Dry, conditioned at 75° F. and 50 percent relative humidity.

W = Wet, conditioned at 100° F. and near 100 percent relative humidity.

[2]Increase in weight = $\frac{\text{Weight after wet conditiong - weight after normal conditioning}}{\text{Weight after normal conditioning}} \times 100$

[3]Fabric for this laminate made by different manufacturer than fabric used in item 1 - 3.

Z M 85625 F

Table 5.--Results of individual shear tests of laminated plastic specimens

Item No.	Panel No.	Laminate	Dry condition[1] Modulus of rigidity	Proportional limit stress	0.2 percent offset yield stress[2]	Ultimate stress	Type of failure[3]	Theoretical ultimate stress[4]	Wet condition[1] Modulus of rigidity	Proportional limit stress	0.2 percent offset yield stress[2]	Ultimate stress	Type of failure[3]	Theoretical ultimate stress[4]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
			1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.		P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.		P.s.i.
1 - 1	5	112 - 114, (2)	652	1,920	3,840	13,430	T	11,010	473	2,130	4,080	11,640	C	6,790
	6	...	672	1,910	4,300	13,760	T	...	484	2,110	4,600	11,690	C	...
1 - 2	60	116 - 114, (2)	608	1,680	3,450	11,260	C	12,140	...	...	...	...	...	7,050
	61	...	536	1,650	3,400	11,600	C	...	...	...	...	...	...	...
1 - 3	12	128 - 114, (2)	596	1,990	3,990	14,220	S and T	12,580	...	...	...	...	...	7,340
	13	...	558	2,900	4,290	14,150	S	...	...	...	...	...	...	...
1 - 4	52	162 - 114, (2)	593	2,110	4,700	11,690	S	9,160	...	...	...	...	...	6,140
	53	...	568	2,340	4,920	11,690	S	...	...	...	...	...	...	...
1 - 6	7	143 - 114, (2)	646	2,870	4,800	13,030	S	9,290	602	2,410	4,140	8,080	S	5,080
	8	...	881	2,160	4,410	11,310	S	...	641	2,420	4,360	10,280	S	...
1 - 7	14	120 - 114, (2)	578	2,530	4,380	14,270	T	12,470	450	1,860	3,480	10,440	C	7,230
	15	...	606	2,160	4,120	13,650	C	...	461	1,420	3,320	10,700	C	...
	15	...	598	2,140	4,190	...	...	...	...	...	...	...	...	...
1 - 8	16	181 - 114, (2)	604	2,660	4,630	16,180	S	12,210	620	1,700	3,640	10,770	C	7,860
	17	...	680	2,230	4,560	14,710	S	...	617	1,730	3,700	11,440	C and S	...
1 - 9	63	182 - 114, (2)	612	1,630	3,840	10,350	C	11,440	...	...	...	...	...	7,150
	64	...	522	1,680	3,310	10,420	C	...	...	...	...	...	...	...
1 - 11	55	184 - 114, (2)	572	2,750	4,100	10,690	T	9,850	482	1,250	2,910	7,220	C and S	6,510
	56	...	650	2,500	4,700	10,340	S	...	500	2,010	3,620	7,820	C and S	...
1 - 12	18	[5]M-503, (2)	890	4,380	...	[5]13,150	...	...	...	...	...	...	...	...
1 - 13	27,28	[6]128 - 114, (2)	610	2,280	4,350	14,020	C	10,670	466	2,190	3,770	9,110	C and S	6,950
	...	...	643	2,060	4,200	13,930	S	...	526	2,000	3,910	9,560	C	...
1 - 14	19	181 - 114, (1)	666	1,730	4,560	...	...	10,690	...	...	...	...	...	6,890
	71	...	450	2,830	4,620	12,400	S and C	...	...	...	...	...	...	...
	20	...	566	1,530	4,590	15,060	S	...	...	...	...	...	...	...
	20	...	594	2,020	4,500	...	...	...	...	...	...	...	...	...
1 - 15	65	181 - 114, (9)	560	1,790	4,510	11,020	S and C	11,150	...	...	...	...	...	8,980
	66	...	561	1,730	4,140	10,990	S and C	...	...	...	...	...	...	...
1 - 19	50	Cotton fabric	336	1,800	3,780	7,610	T	5,110	...	...	...	...	...	4,740
	51	...	324	2,070	3,780	7,600	T	...	...	...	...	...	...	...

[1]Dry specimens tested shortly after specimen was removed from hot press. Wet specimens conditioned at 80° F. and 97 percent relative humidity.

[2]0.2 percent offset yield stress is stress at point where strain deviates 0.002 inch per inch from initial straight line of stress-strain curve in shear.

[3]Type of failure indicated as primarily S (shear), T (tension), or C (compression) or a combination thereof.

[4]Theoretical ultimate stress calculated from results of tension tests at 0°, 45°, and 90°.

[5]Poor failure. Ultimate stress probably higher than value given.

[6]Fabric for this laminate made by different manufacturer than fabric used in item 1 - 3.

Z M 65626 F

Table 6.--Ratio of wet properties to dry properties of laminated plastics, based on tests in tension, compression, and bending

Item No.	Angle of loading	Panel No.	Laminate	Tension					Compression			Bending		
				Modulus of elasticity		Proportional limit		Ultimate stress	Modulus of elasticity	Proportional limit	Ultimate stress	Modulus of elasticity	Proportional limit	Modulus of rupture
				Initial	Secondary	Initial	Secondary							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	Degrees			Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1 - 1	0	5, 6	112 - 114, (2)	....	97	....	80	75	88	86	77	84	91	65
	90			....	87	....	55	78	89	81	66	84	87	62
	45			....	51	....	85	63	....	....	....	....	....	....
1 - 2	0	60, 61	116 - 114, (2)	79	90	87	73	78	88	66	58	90	70	62
	90			88	94	73	58	71	82	64	53	88	63	63
	45			....	57	....	62	59	....	....	....	....	....	....
1 - 3	0	12, 13	128 - 114, (2)	88	97	124	67	76	78	74	59	85	59	56
	90			86	101	76	68	76	79	63	58	83	71	58
	45			....	57	....	55	60	....	....	....	....	....	....
1 - 4	0	52, 53	162 - 114, (2)	....	88	....	34	72	92	44	58	84	75	65
	90			....	99	....	39	79	85	41	58	84	96	72
	45			....	69	....	58	68	....	....	....	....	....	....
1 - 6	0	7, 8	143 - 114, (2)	....	88	....	90	81	94	77	63	91	46	52
	90			61	100	80	74	85	62	93	64	66	76	80
	45			....	48	....	83	63	....	....	....	....	....	....
1 - 7	0	14, 15	120 - 114, (2)	....	96	....	58	84	88	83	70	84	85	61
	90			....	85	....	68	82	83	89	67	82	87	61
	45			....	42	....	69	60	....	....	....	....	....	....
1 - 8	0	16, 17	181 - 114, (2)	94	101	72	84	83	88	82	69	87	76	61
	90			99	106	105	87	85	85	76	61	87	86	63
	45			....	69	....	71	66	....	....	....	....	....	....
1 - 9	0	63, 64	182 - 114, (2)	96	104	105	85	88	93	67	64	94	64	67
	90			91	99	100	84	83	92	69	71	91	79	70
	45			....	68	....	73	64	....	....	....	....	....	....
1 - 11	0	55, 56	184 - 114, (2)	85	82	97	74	86	90	50	61	99	62	67
	90			88	89	111	78	89	89	54	64	90	72	67
	45			....	62	....	68	67	....	....	....	....	....	....
1 - 12	0	18	M-503, (2)	....	94	....	88	80	81	34	44	70	100	52
	90			....	94	....	81	82	80	33	47	67	85	49
	45			....	97	....	82	80	....	....	....	....	....	....
	0	68	M-503, (2)	....	83	....	91	76	73	45	43	85	61	55
	90			....	90	....	69	76	74	46	40	76	93	58
	45			....	80	....	83	75	....	....	....	....	....	....
1 - 13	0	27, 28	128 - 114, (2)	91	97	90	67	76	78	62	50	80	56	59
	90			90	107	109	74	83	77	61	51	80	64	59
	45			....	62	....	78	67	....	....	....	....	....	....
1 - 14	0	19, 20	181 - 114, (1)	96	100	103	91	91	95	68	73	86	97	63
	90			99	101	92	82	86	84	89	63	85	74	61
	45			....	64	....	73	66	....	....	....	....	....	....
1 - 15	0	65, 66	181 - 114, (9)	97	98	118	104	96	105	100	97	106	83	87
	90			99	97	116	102	98	99	76	96	110	81	90
	45			....	95	....	105	82	....	....	....	....	....	....
1 - 19	0	50, 51	Cotton fabric	....	77	....	72	91	84	46	68	78	84	91
	90			....	72	....	62	95	83	43	64	76	77	94
	45			....	72	....	58	93	....	....	....	....	....	....
Average ratios for 10 laminates[1] made of glass cloth and resin 2														
0°				89	94	96	71	80	88	69	63	88	68	62
90°				86	97	93	68	81	82	69	61	84	78	66
45°				....	58	....	70	64	....	....	....	....	....	....

[1] Excludes items 1 - 12, 1 - 14, 1 - 15, and 1 - 19.

Z M 85627 F

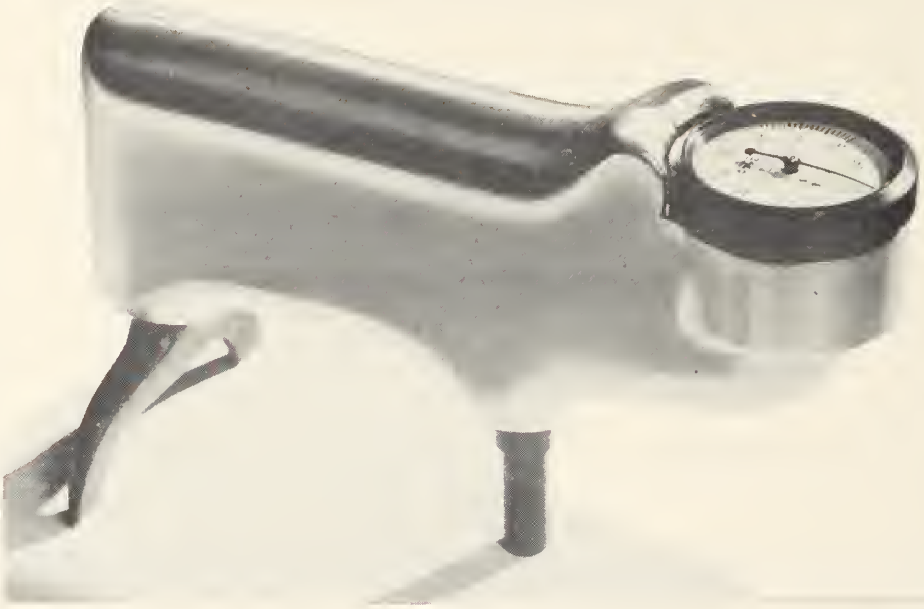
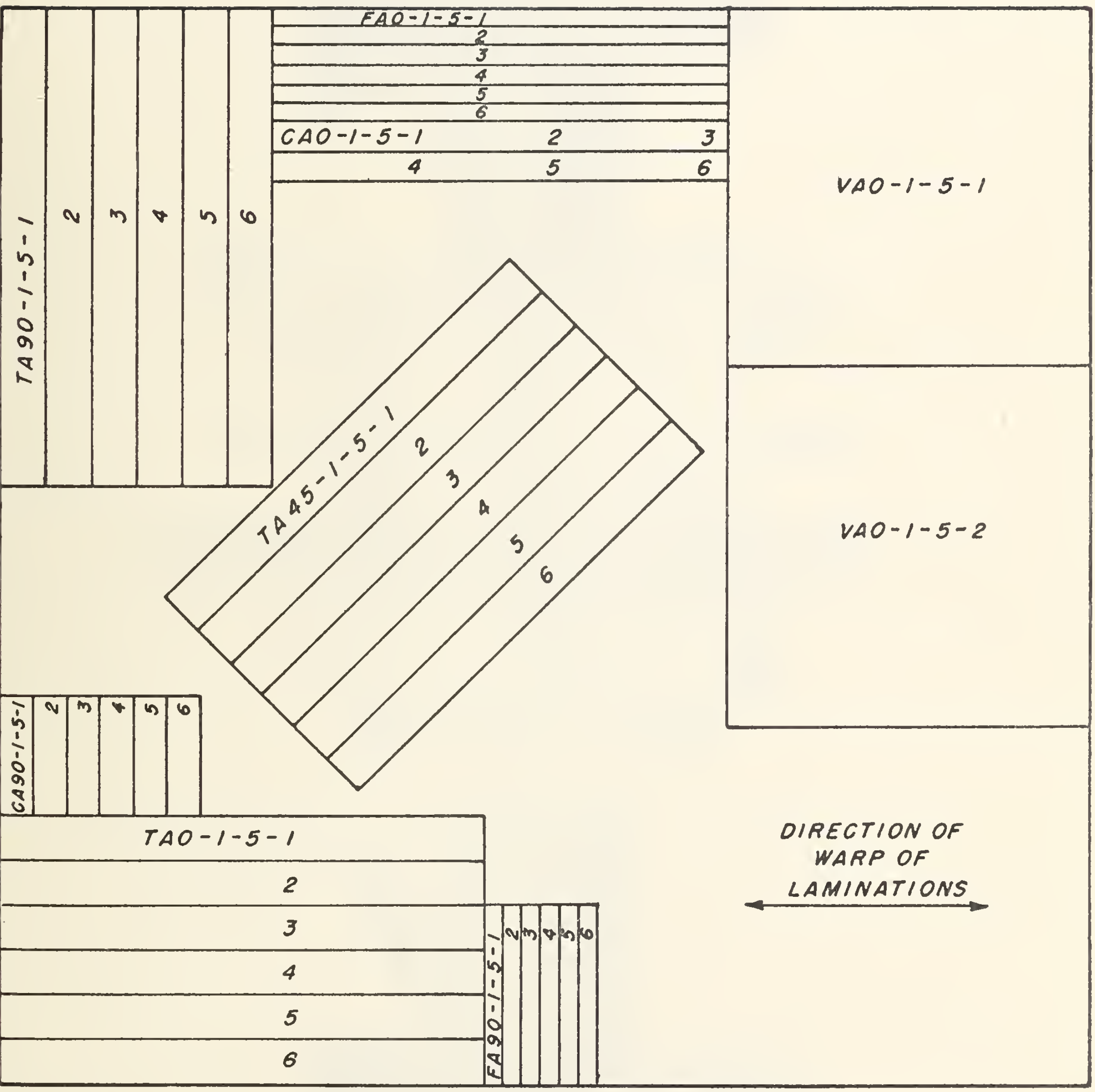


Figure 1. --Barcol hardness tester used for comparing the surface hardness of various plastic laminates.

ZM 79027 F



Z M 85389 F

Figure 2.--Cutting diagram for laminated plastic specimens, from 1/4- by 36- by 36-inch panels.

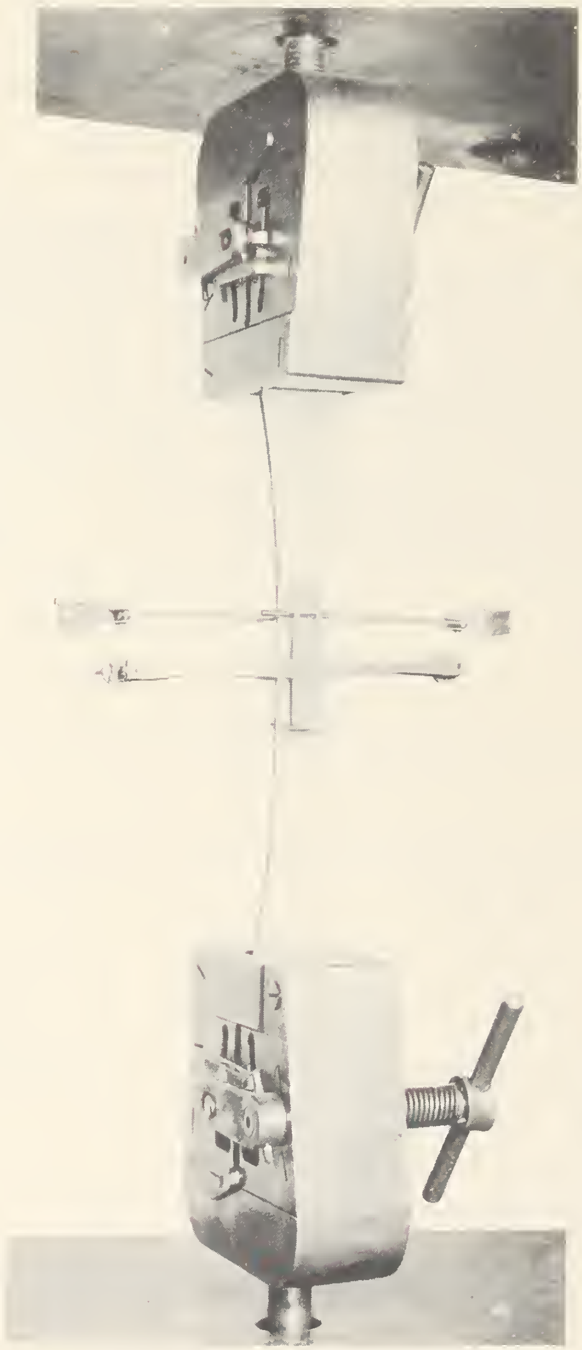


Figure 3.--Tensile test used in testing plastic laminate specimens.

ZM 78989 F

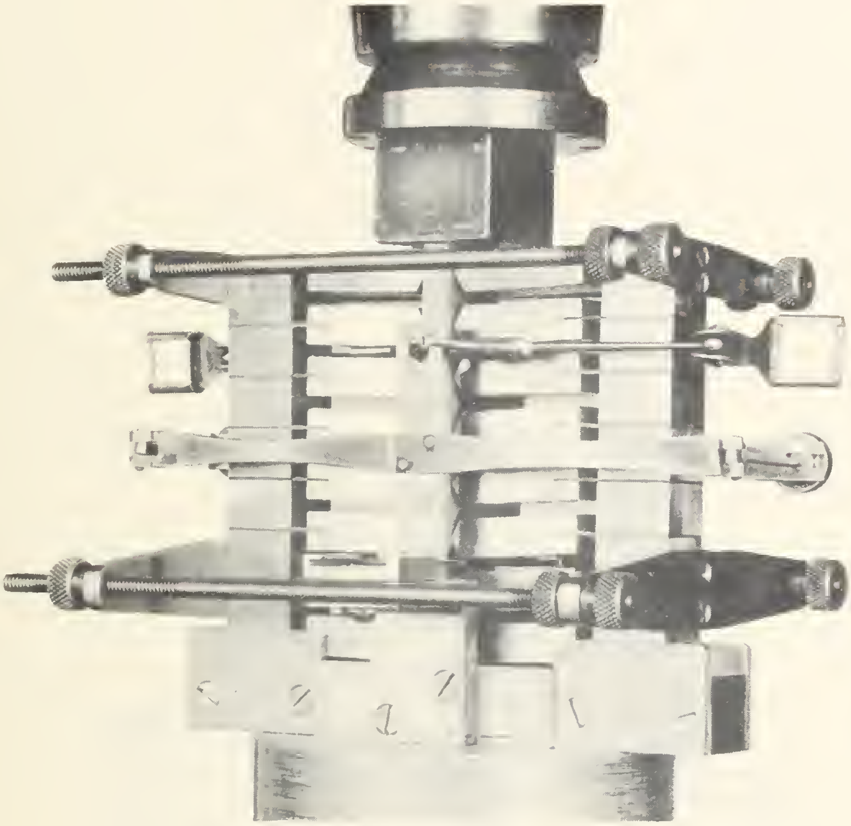


Figure 4. --Compression pack test of the type used in testing plastic laminate specimens.

ZM 81129 F

Figure 5. --Typical failure of plastic laminate compression specimen.

ZM 78990 F

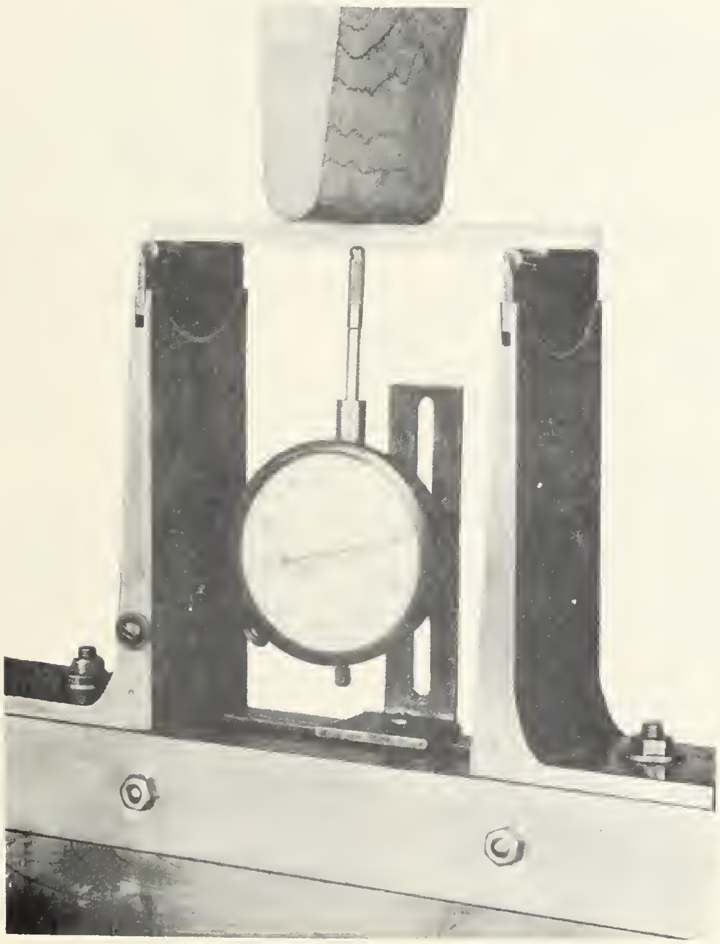


Figure 6.--Static bending set-up used in testing plastic laminate specimens.

ZM 81128 F

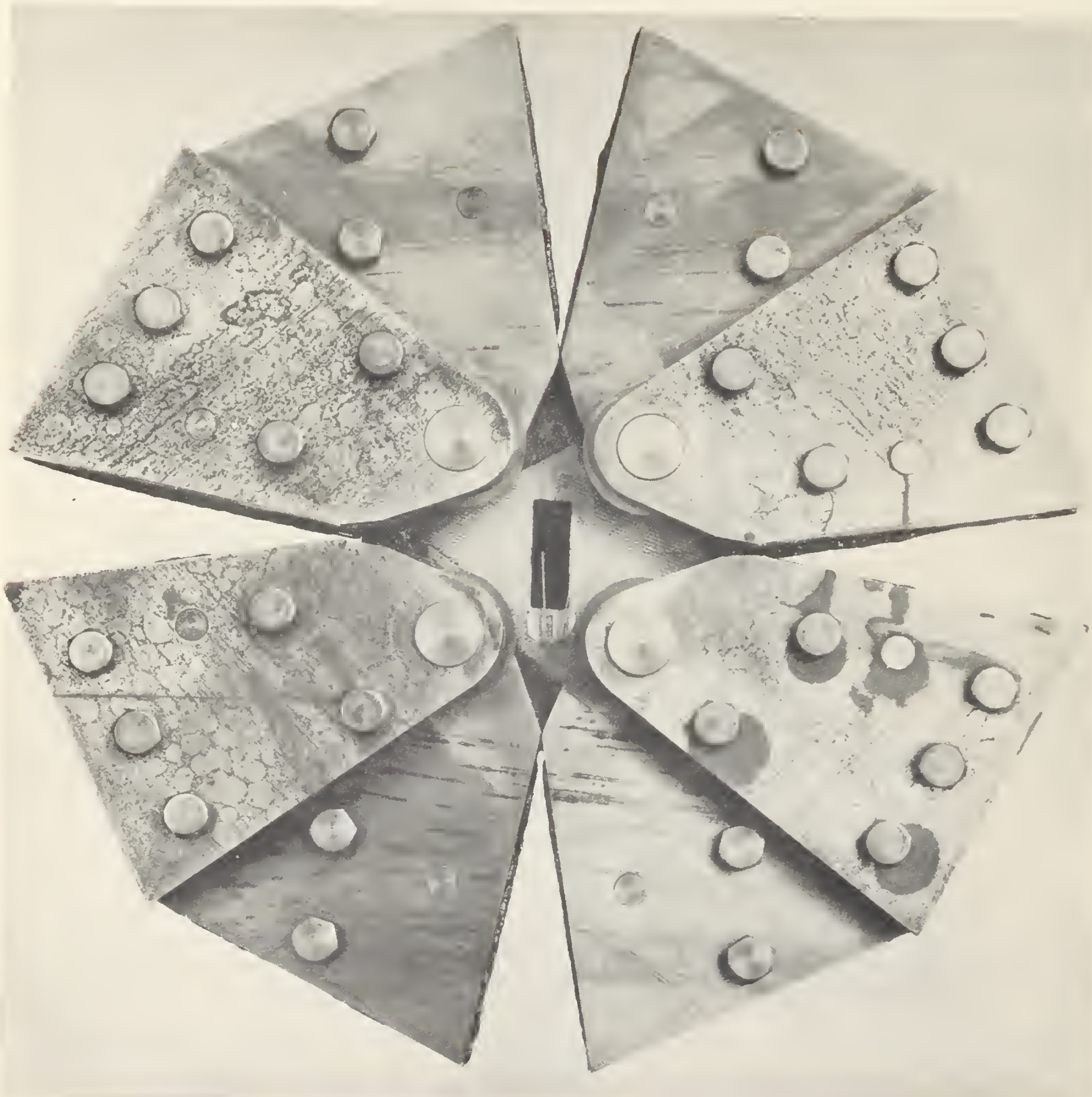
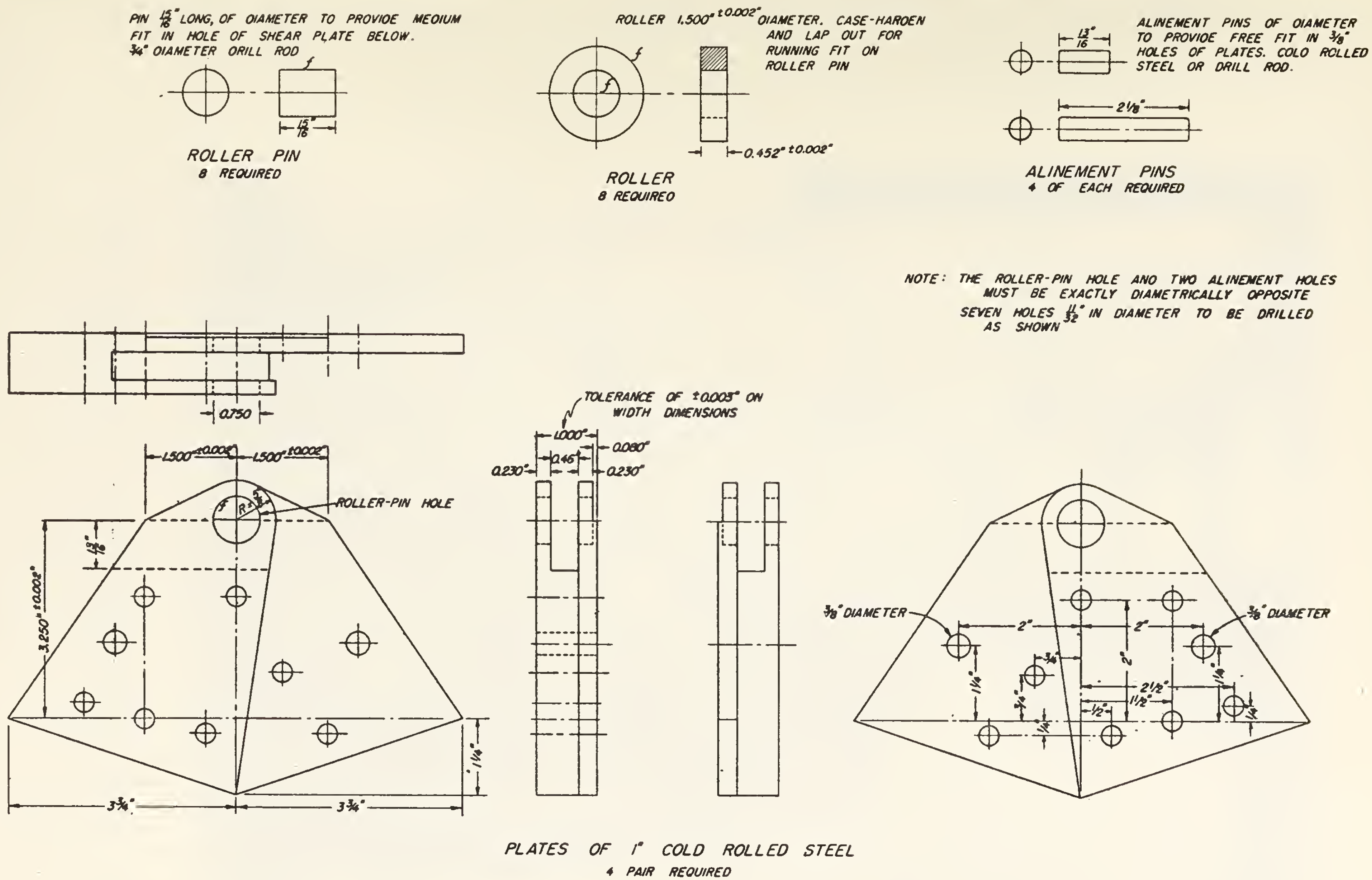


Figure 7.--Panel shear apparatus used in testing plastic laminates.

ZM 80082.F



Z M 80098 F

Figure 8. --Drawing of 3-inch panel shear apparatus used in testing plastic laminate specimens.

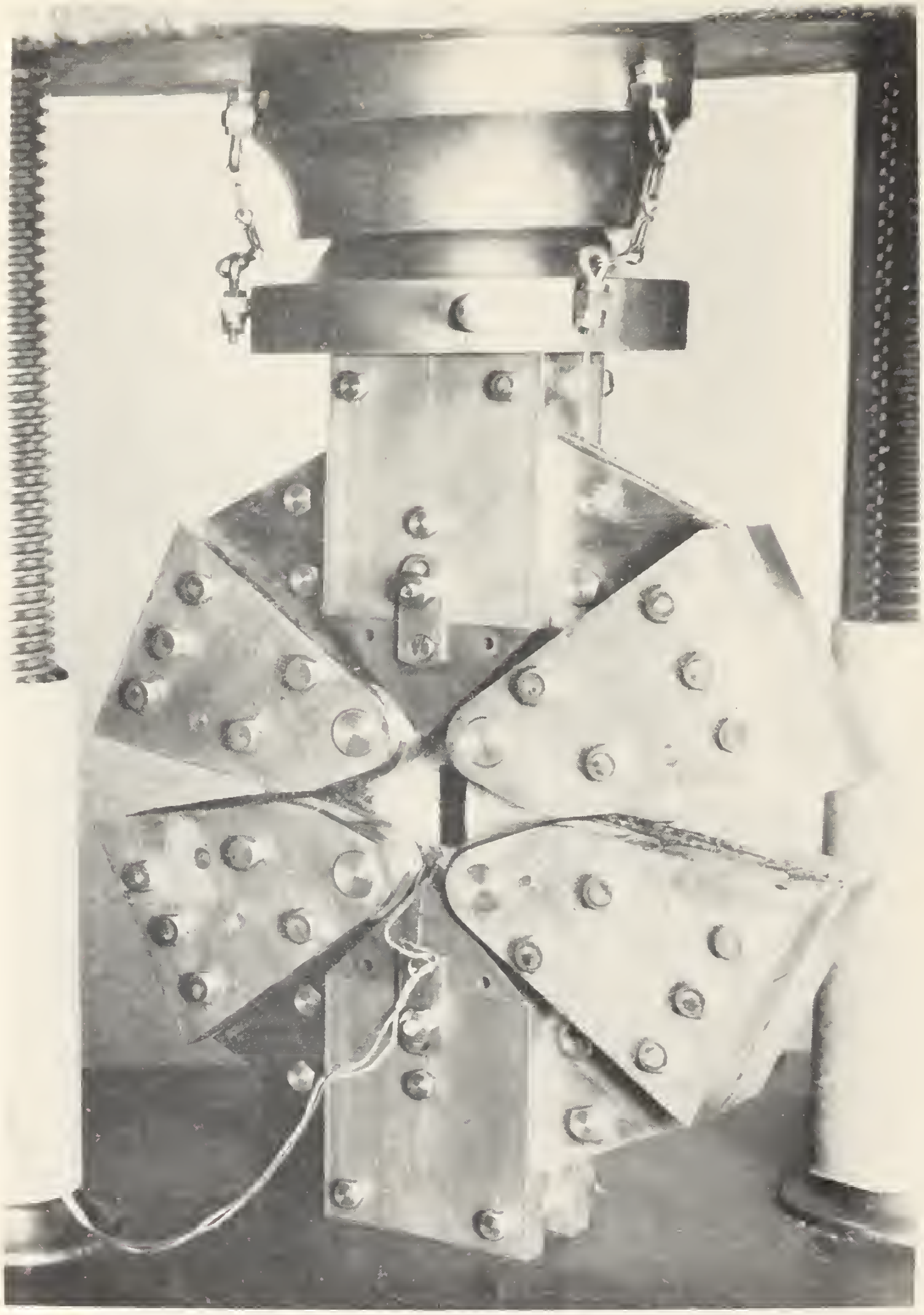
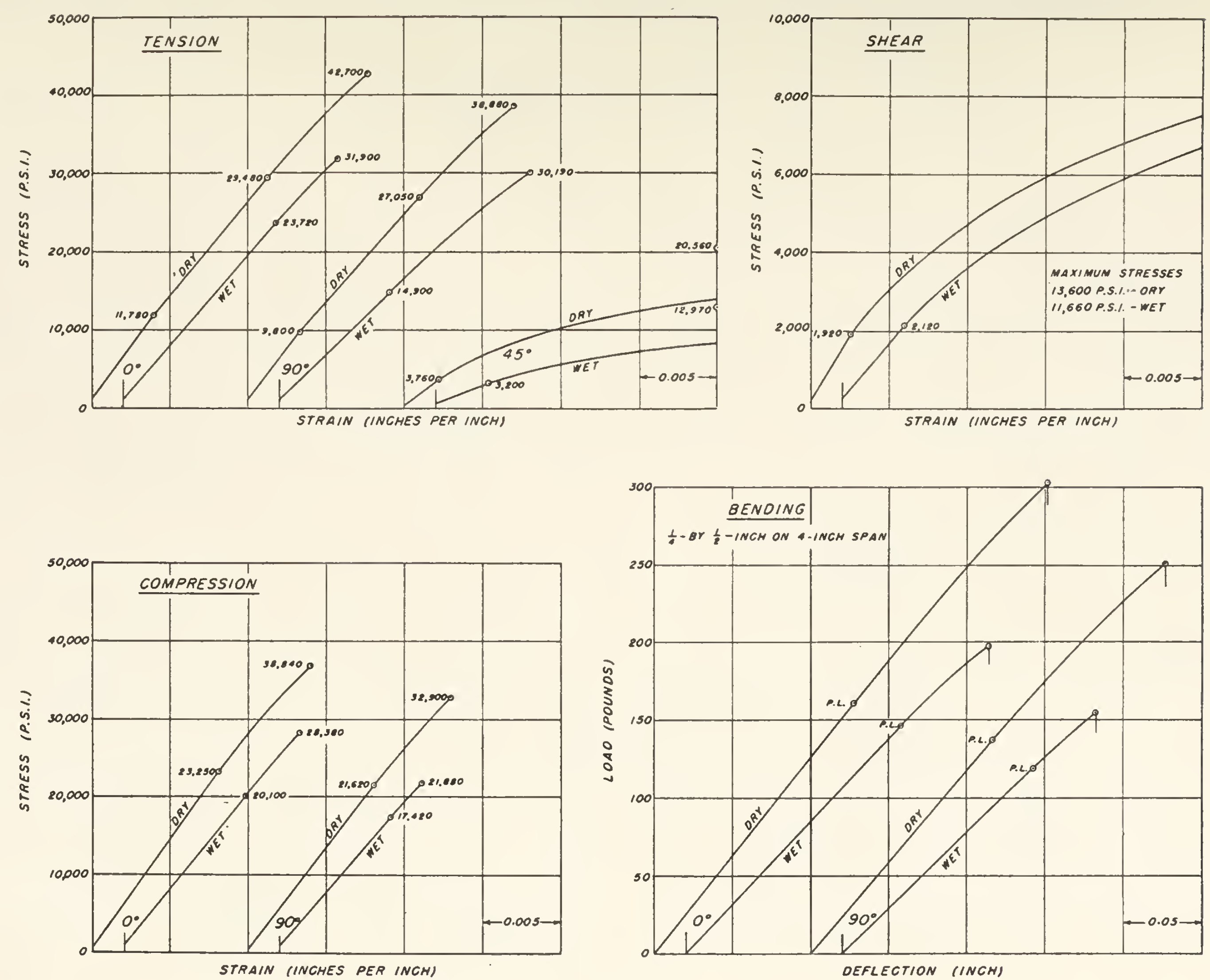


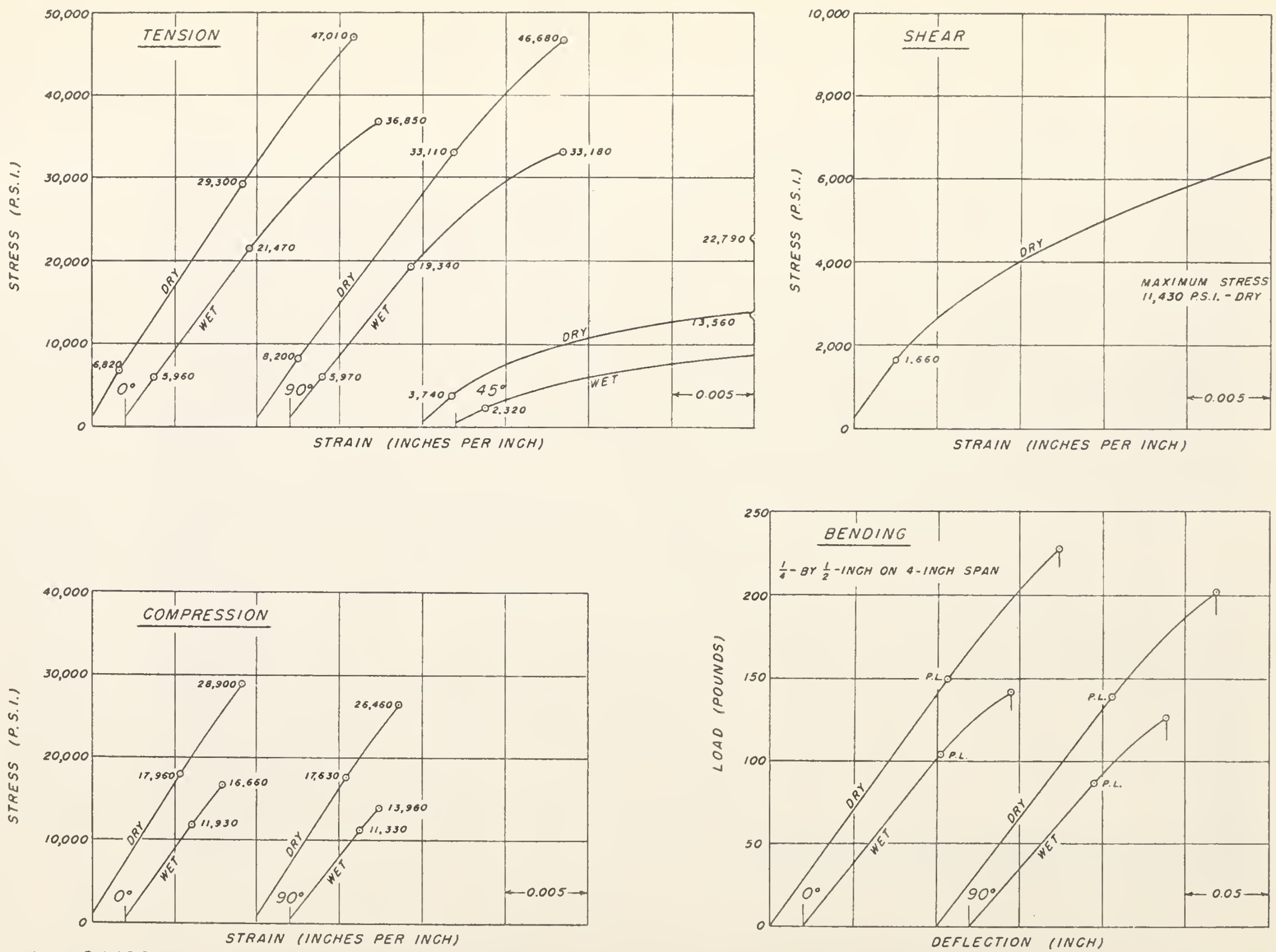
Figure 9.--Method of testing plastic laminate panel shear specimens. Strain measurements can be made with metalectric gages (shown) or with other types.

ZM 77405 F



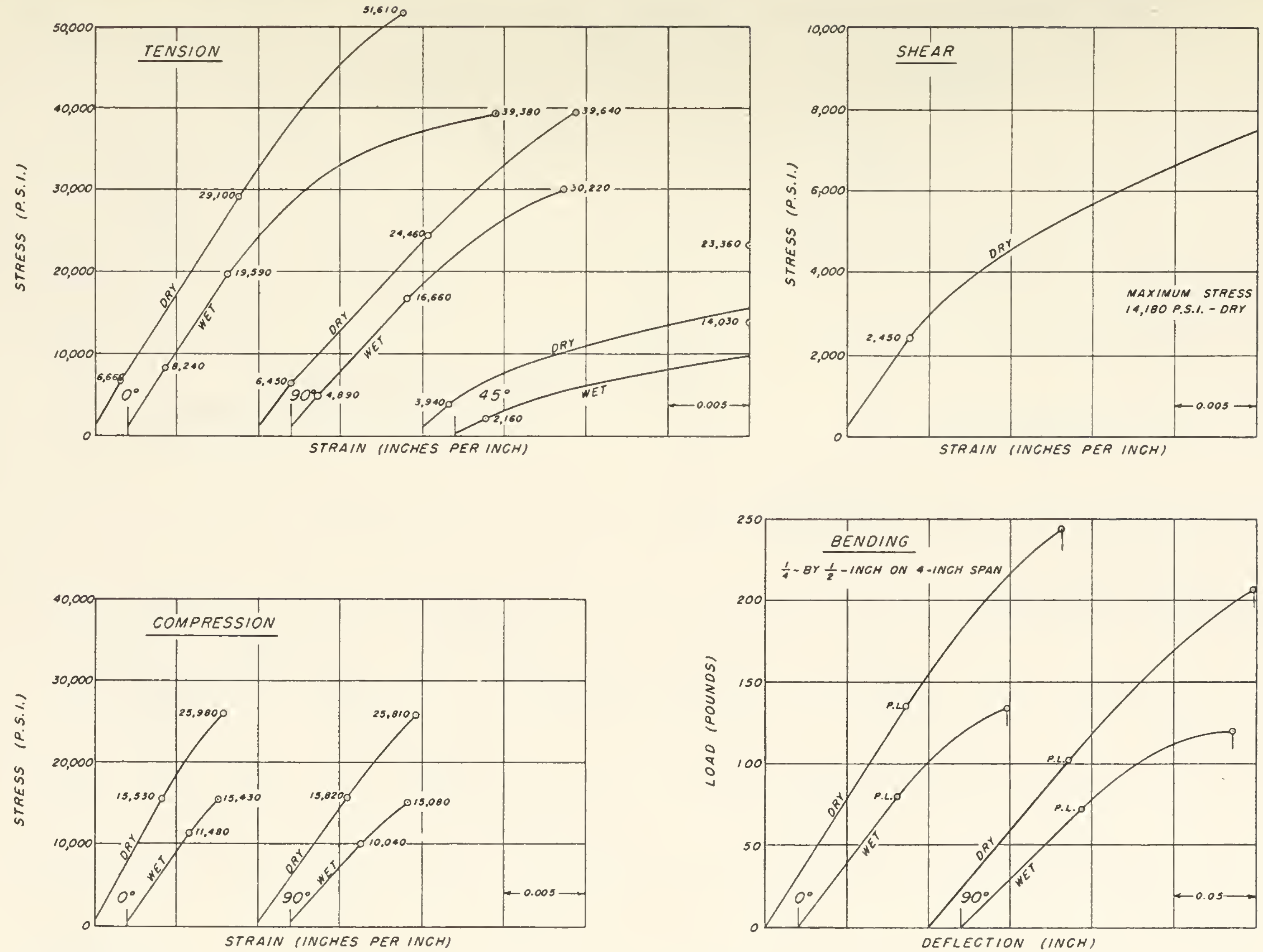
Z M 85395 F

Figure 10.--Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of 112-114 glass fabric and resin 2.



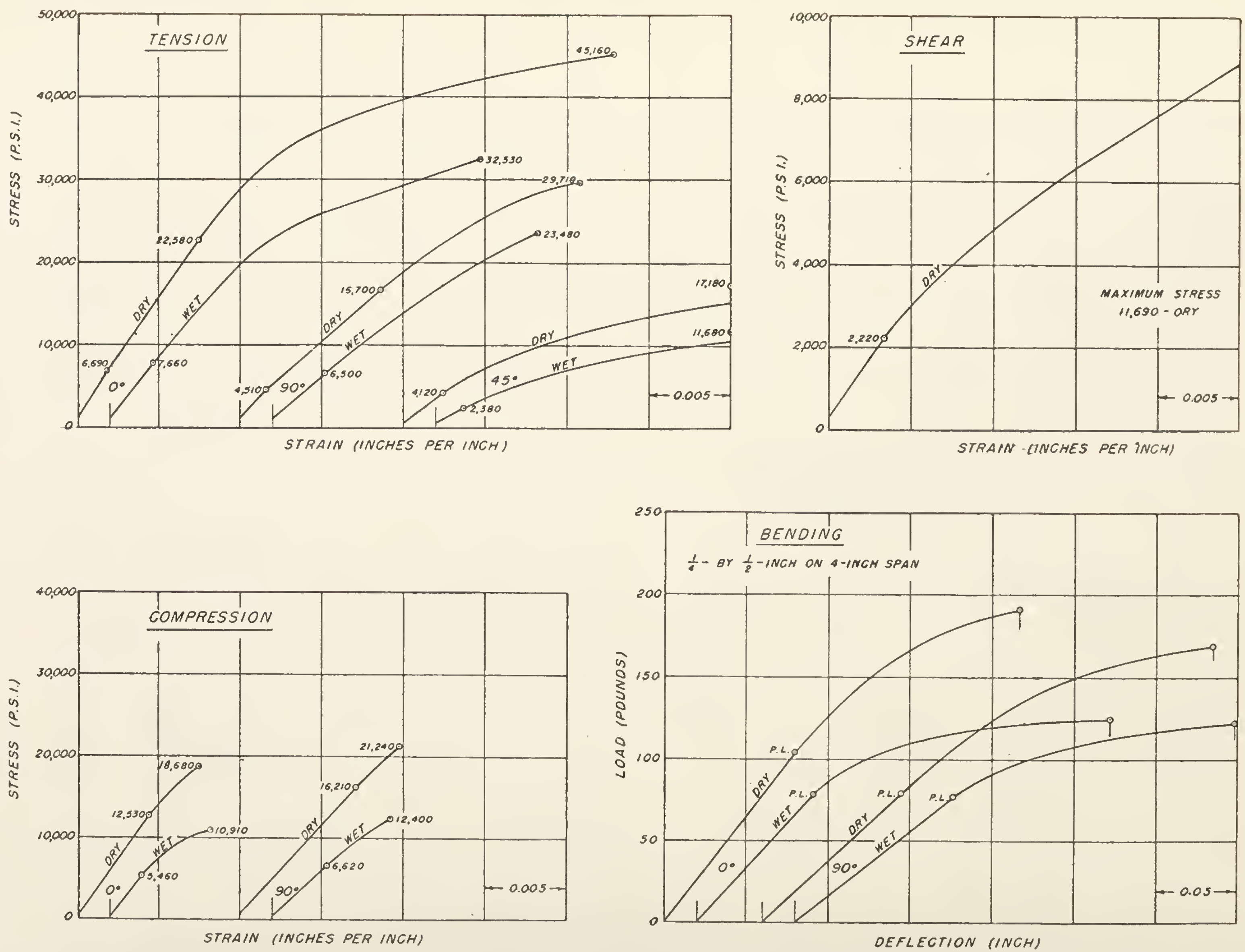
Z M 85401 F

Figure 11. --Average stress-strain curves in tension, compression, and shear and load-deflection curves in bending for laminate made of 116-114 glass fabric and resin 2.



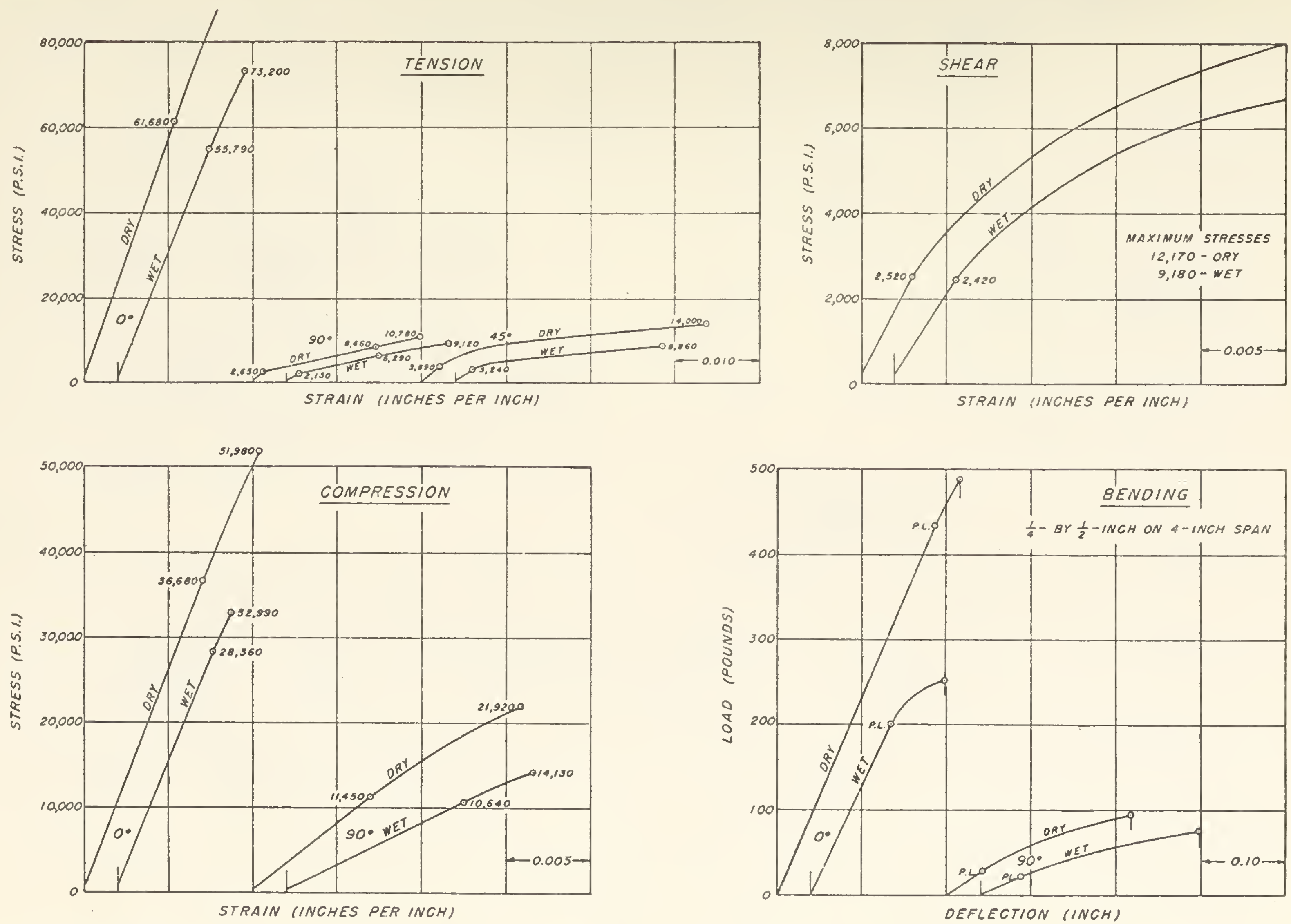
Z M 85393 F

Figure 12. --Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of 128-114 glass fabric and resin 2.



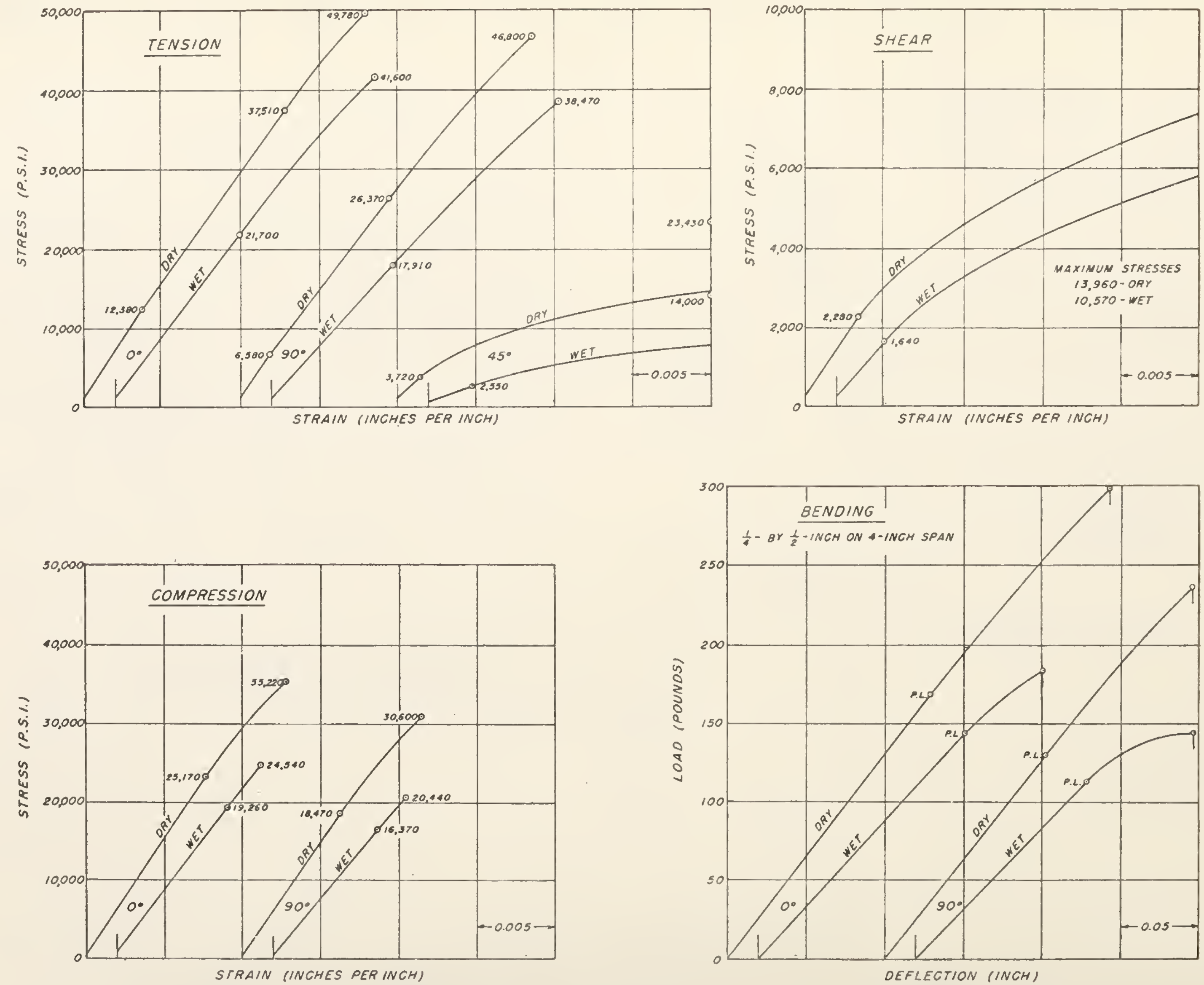
ZM 85392 F

Figure 13. --Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of 162-114 glass fabric and resin 2.



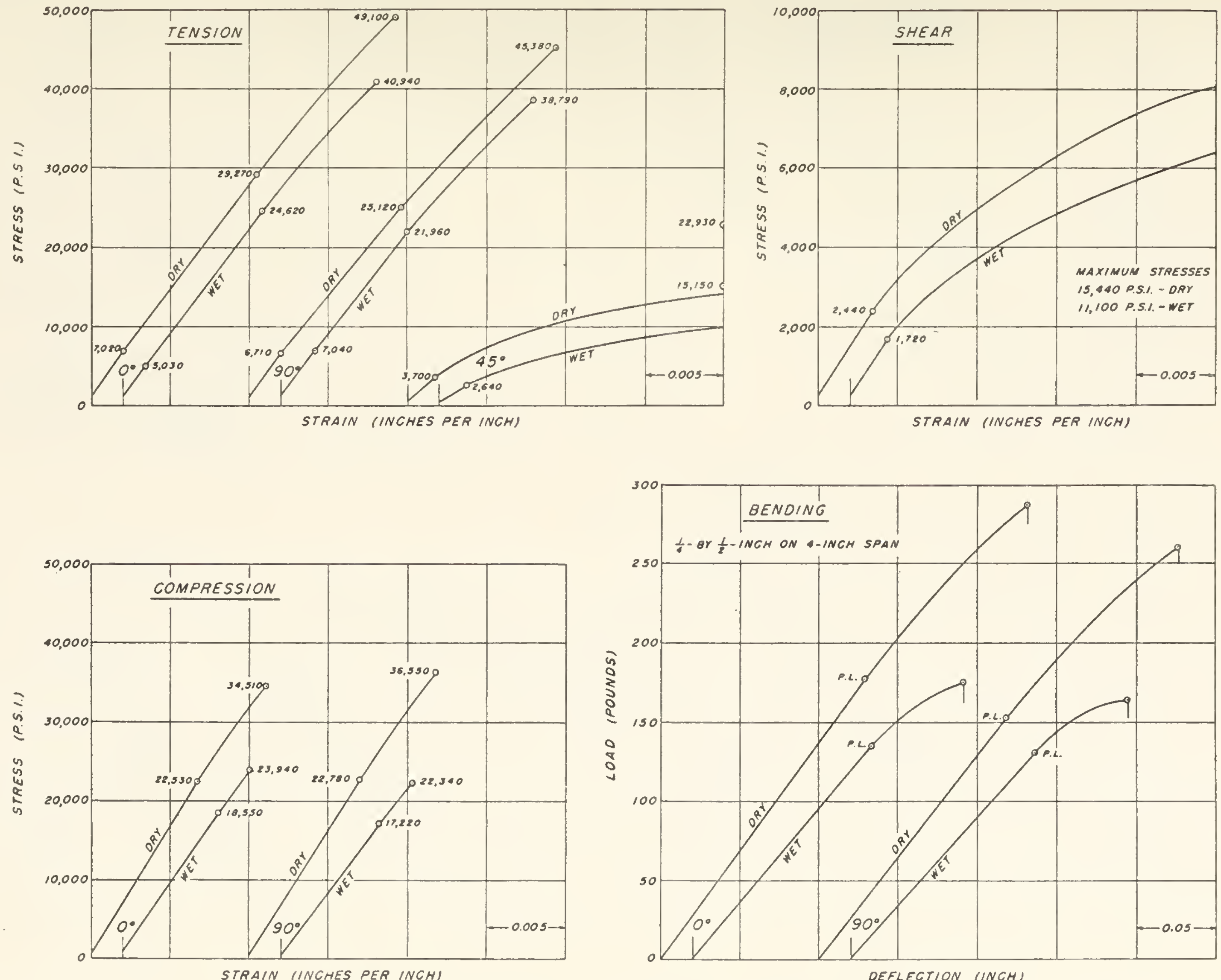
Z M 85403 F

Figure 14. --Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of 143-114 glass fabric and resin 2.



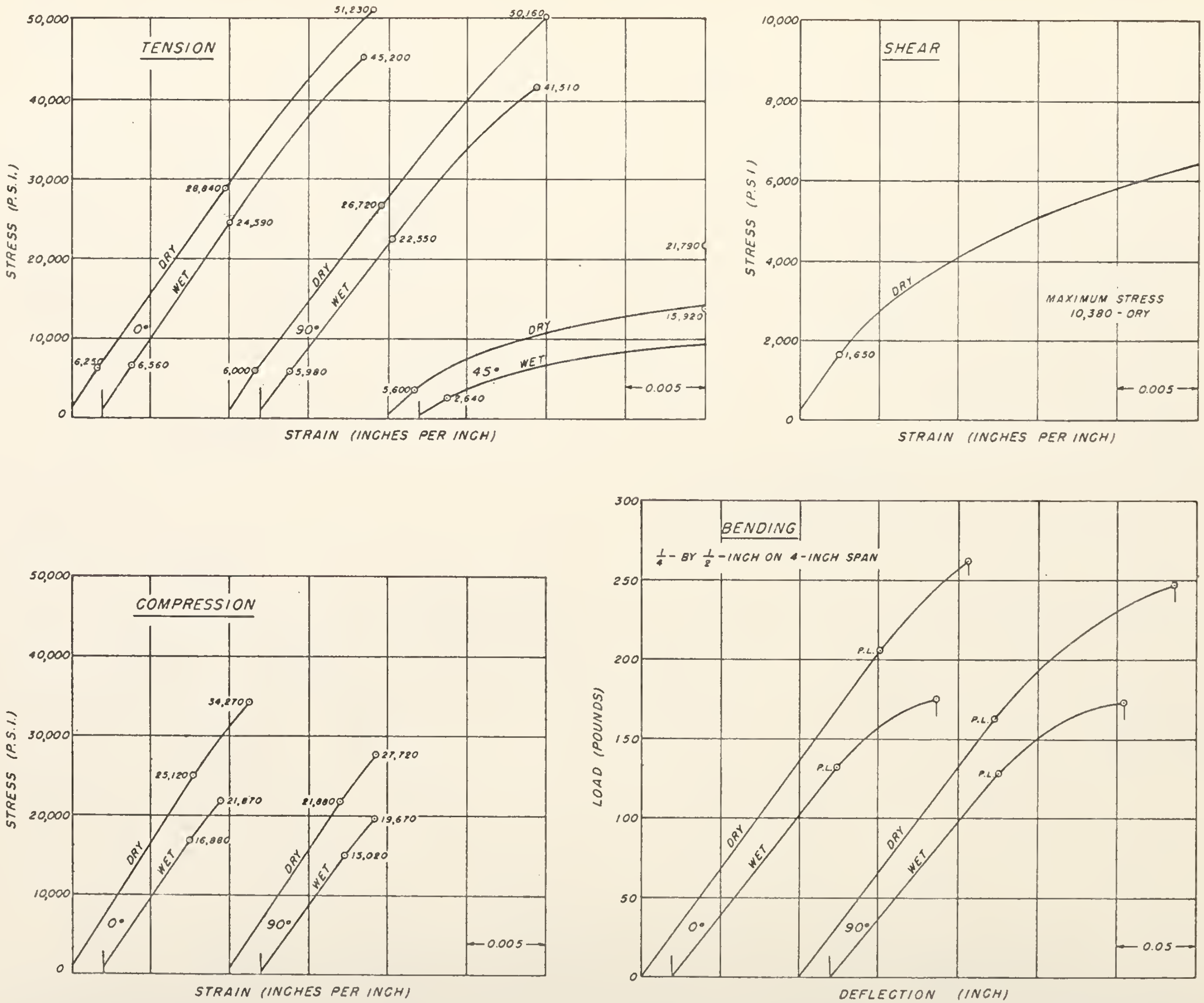
Z M 85399 F

Figure 15. --Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of 120-114 glass fabric and resin 2.



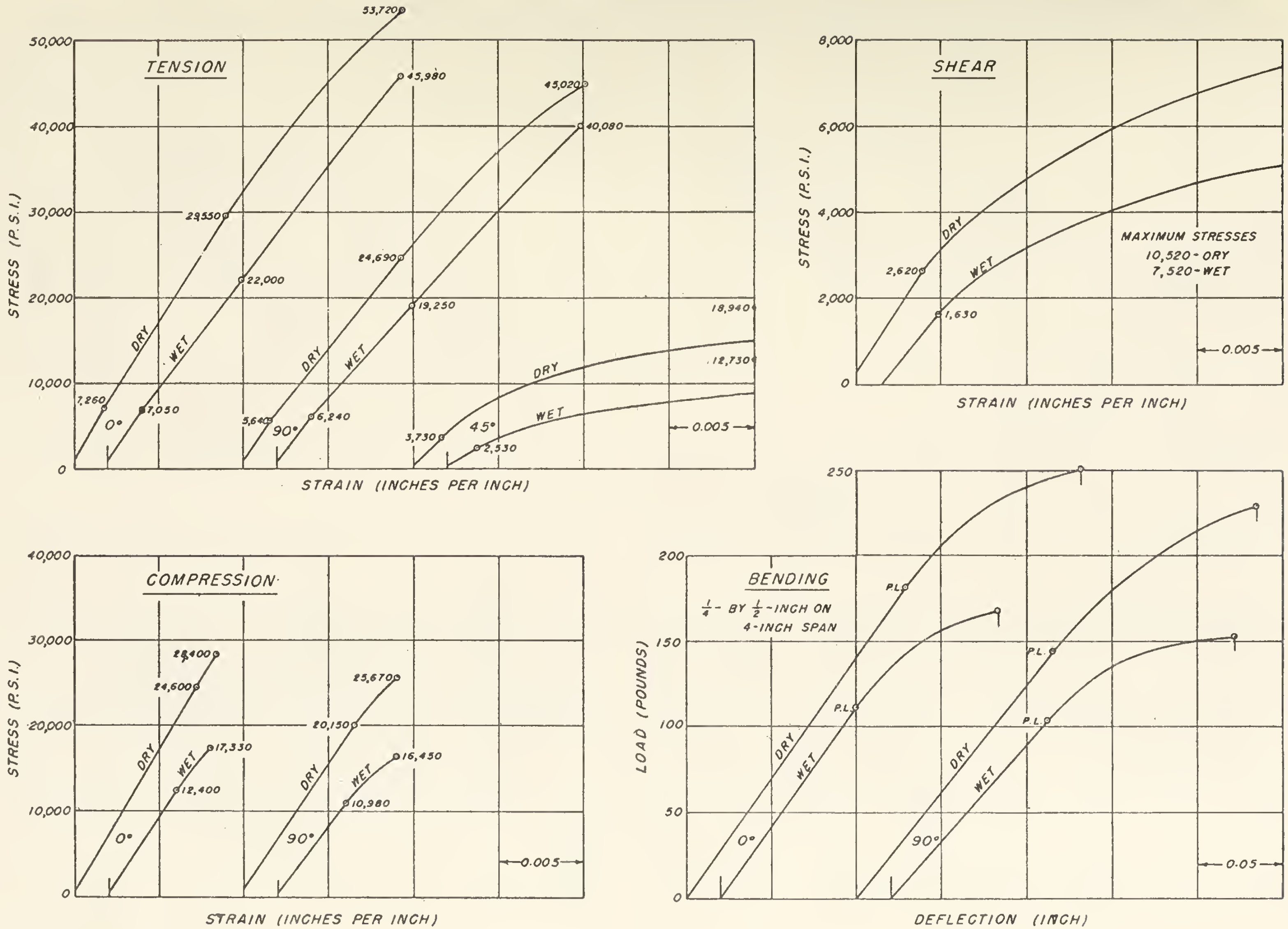
Z M 85394 F

Figure 16. --Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of 181-114 glass fabric and resin 2.



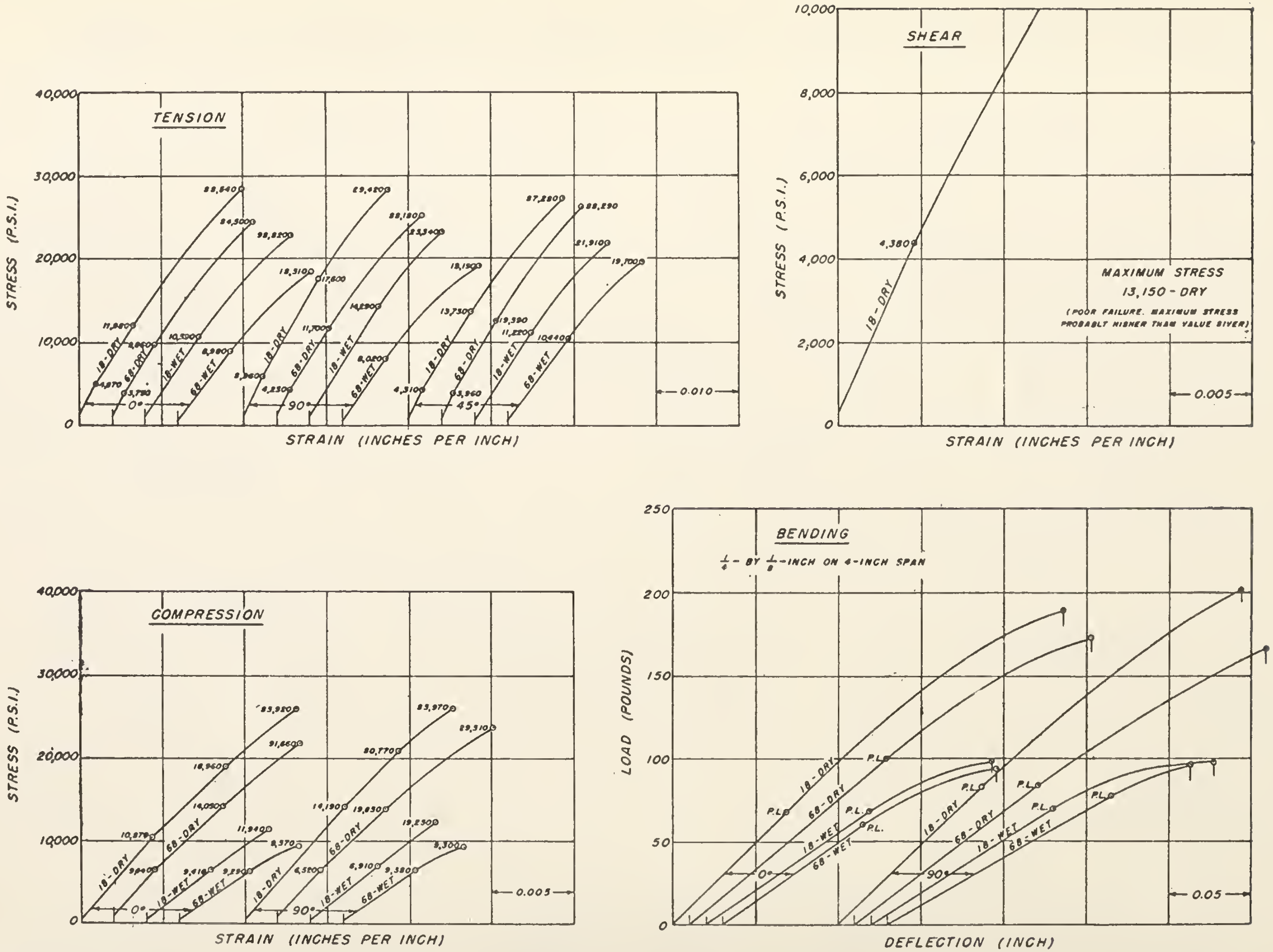
Z M 85397 F

Figure 17. --Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of 182-114 glass fabric and resin 2.



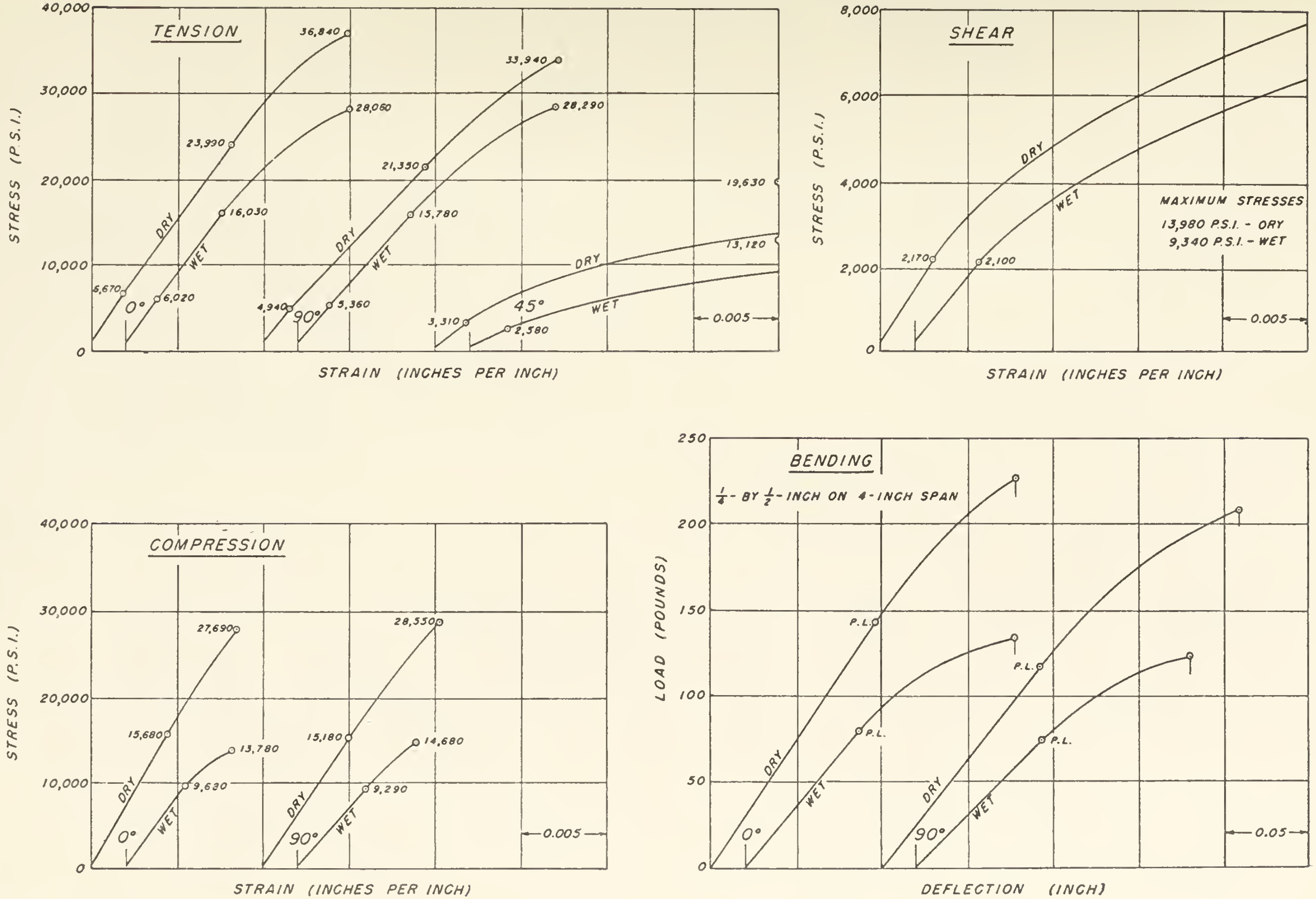
Z M 85402 F

Figure 18. --Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of 184-114 glass fabric and resin 2.



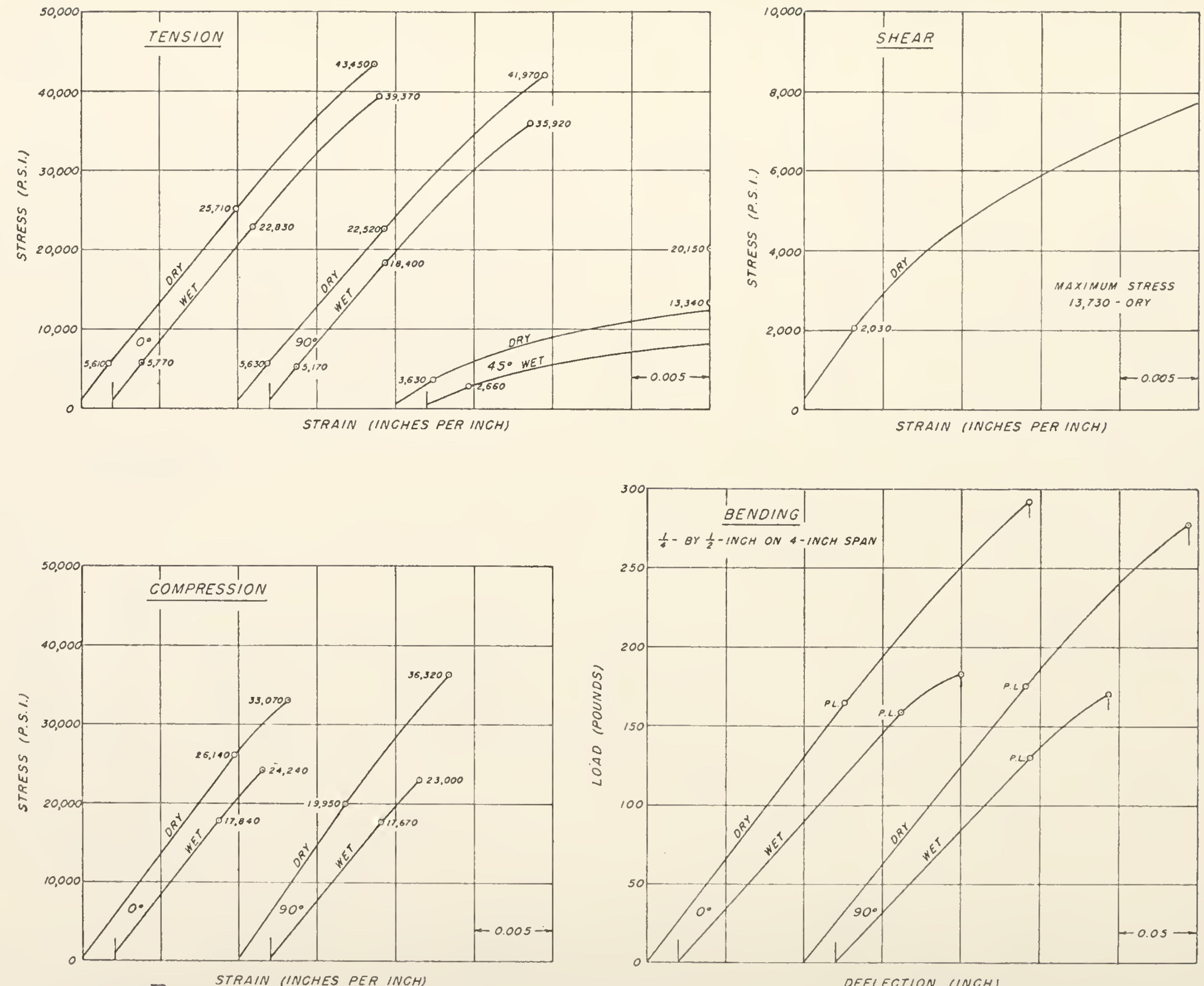
Z M 85396 F

Figure 19. --Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of M-503 glass-fiber mat and resin 2. Curves shown for both panels 18 and 68.



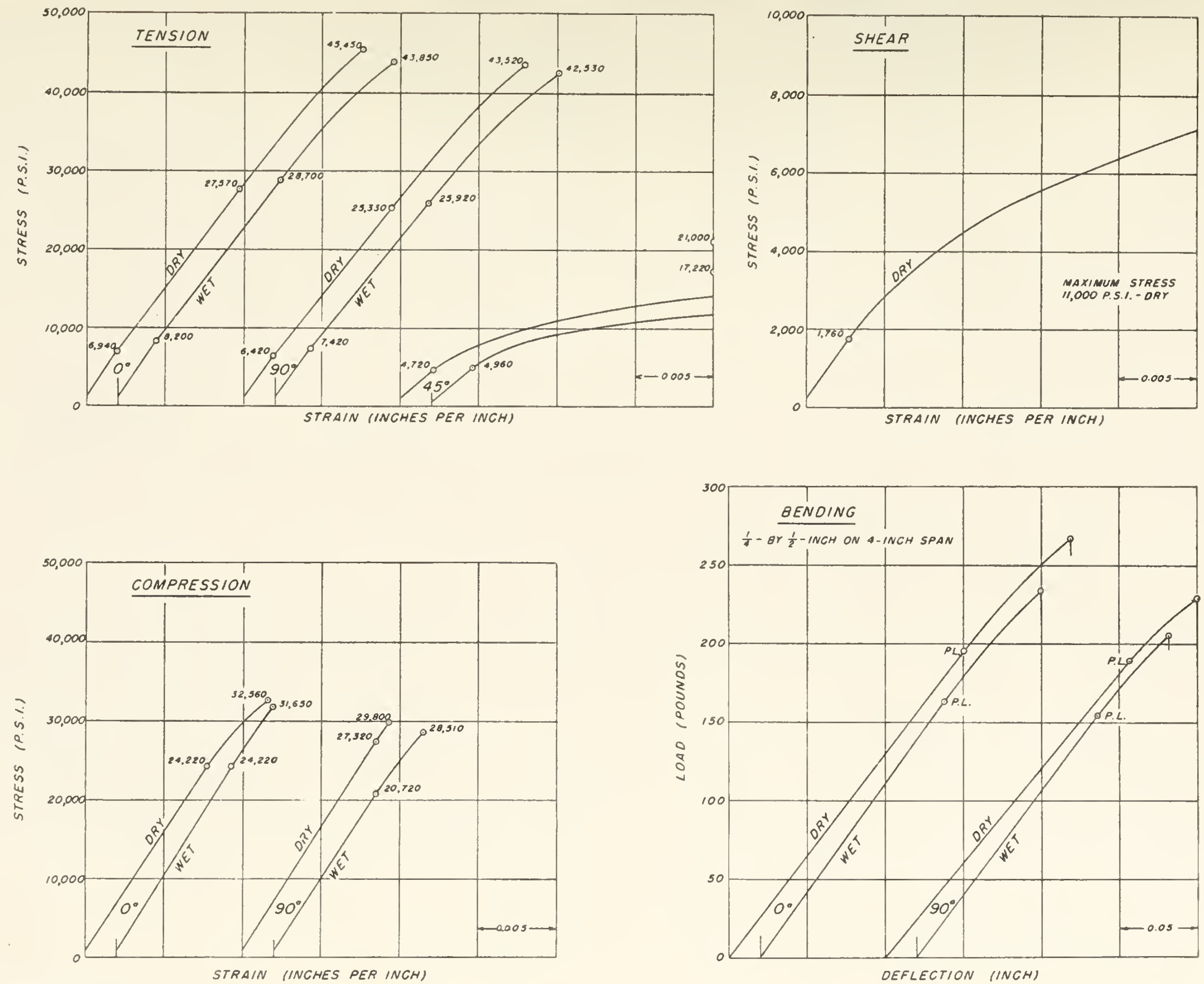
Z M 85398 F

Figure 20. --Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of 128-114 glass fabric and resin 2. (The 128-114 fabric represented by this figure was made by a different manufacturer than was that for which results are given in figure 12.)



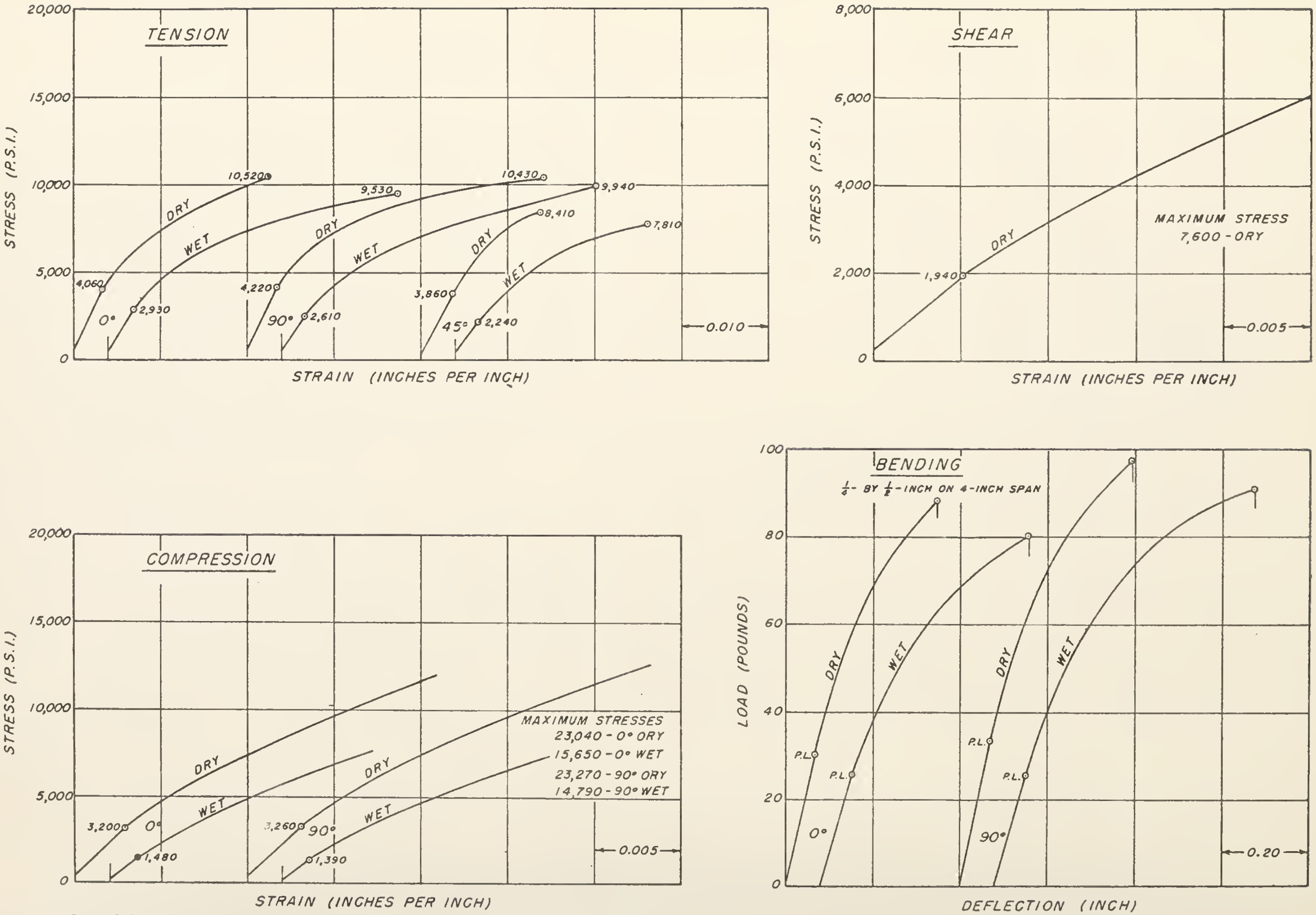
Z M 85391 F

Figure 21. --Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of 181-114 glass fabric and resin 1.



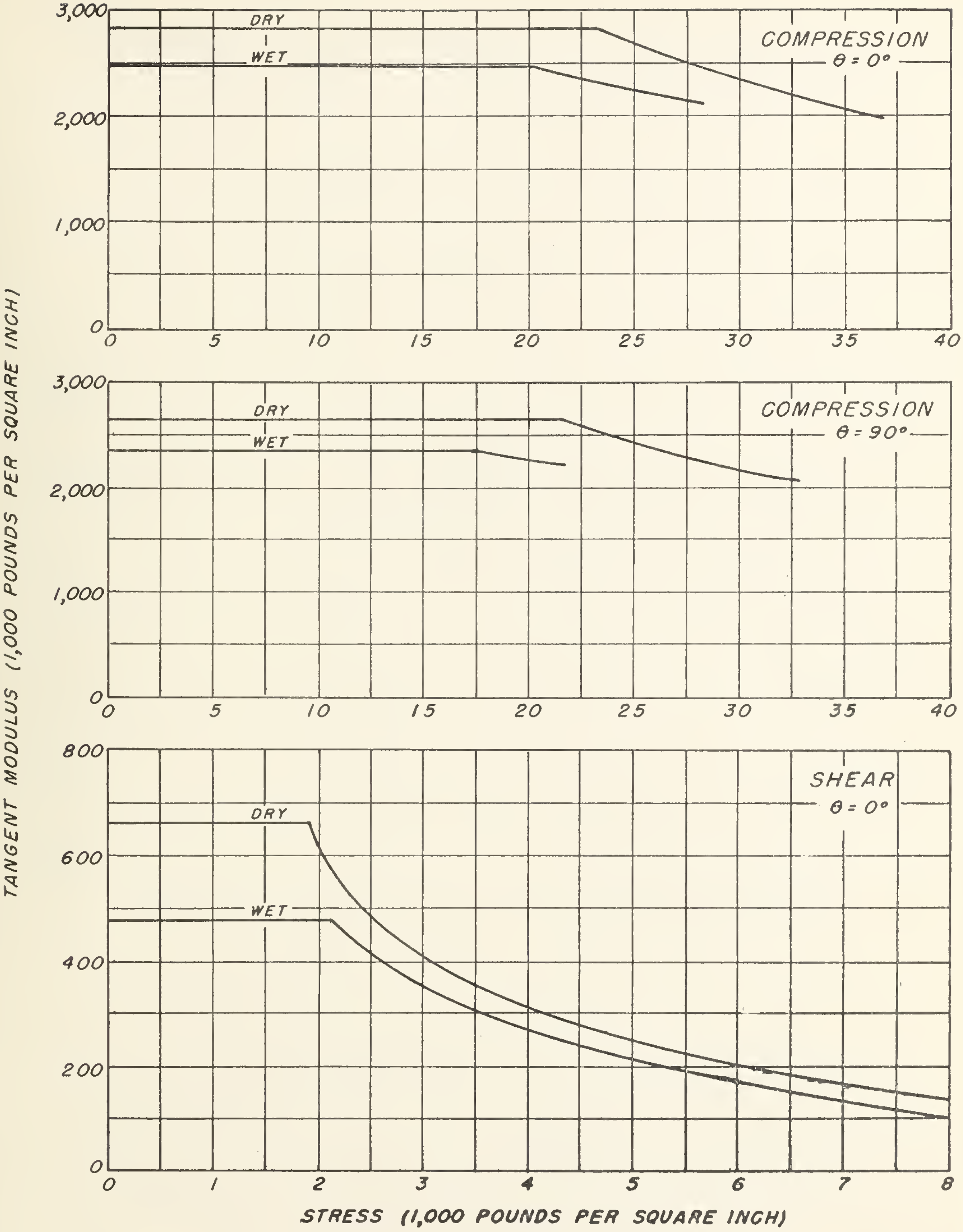
Z M 85400 F

Figure 22. --Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of 181-114 glass fabric and resin 9.



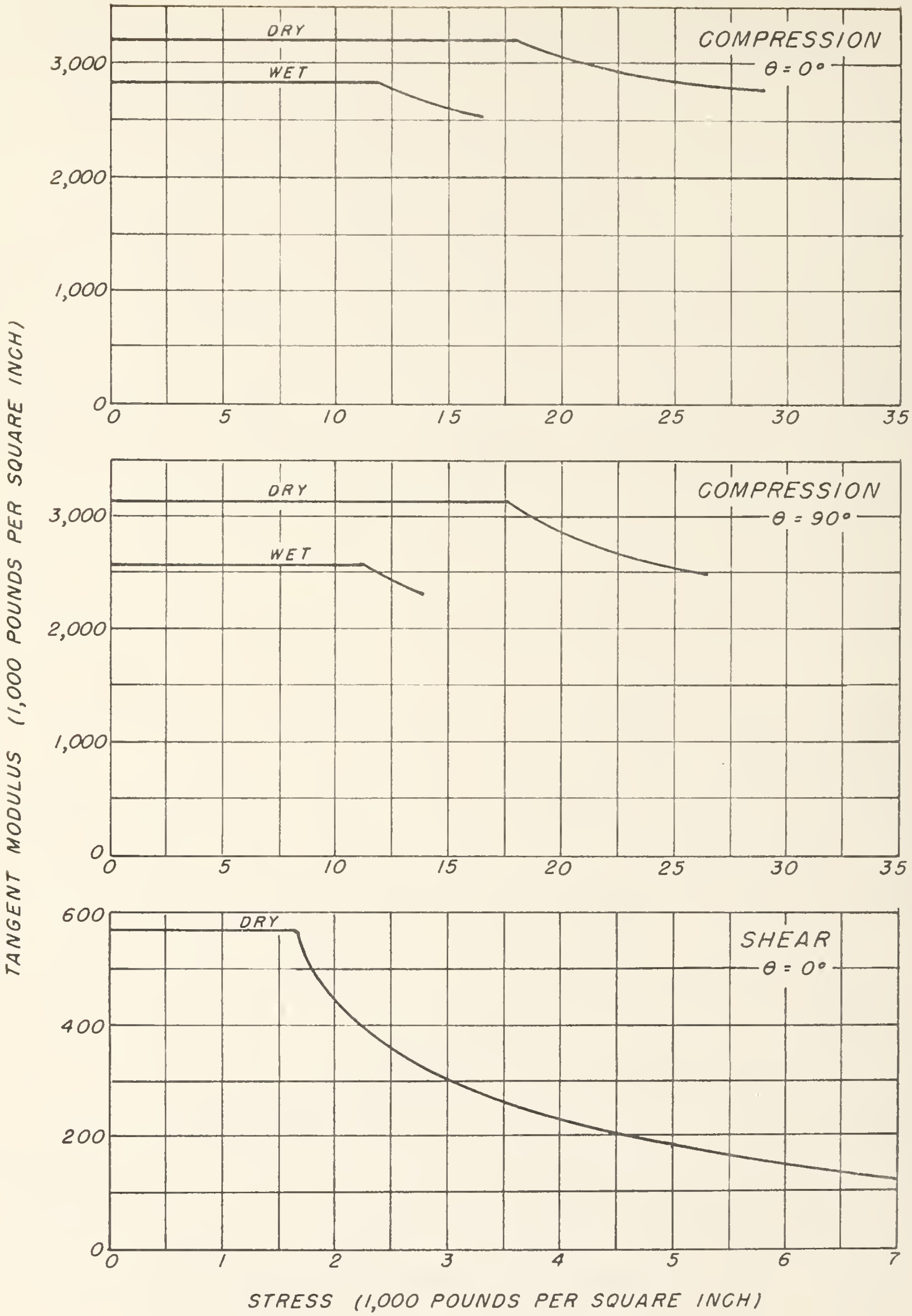
Z M 85390 F

Figure 23. --Average stress-strain curves in tension, compression, and shear, and load-deflection curves in bending for laminate made of cotton fabric and phenolic resin.



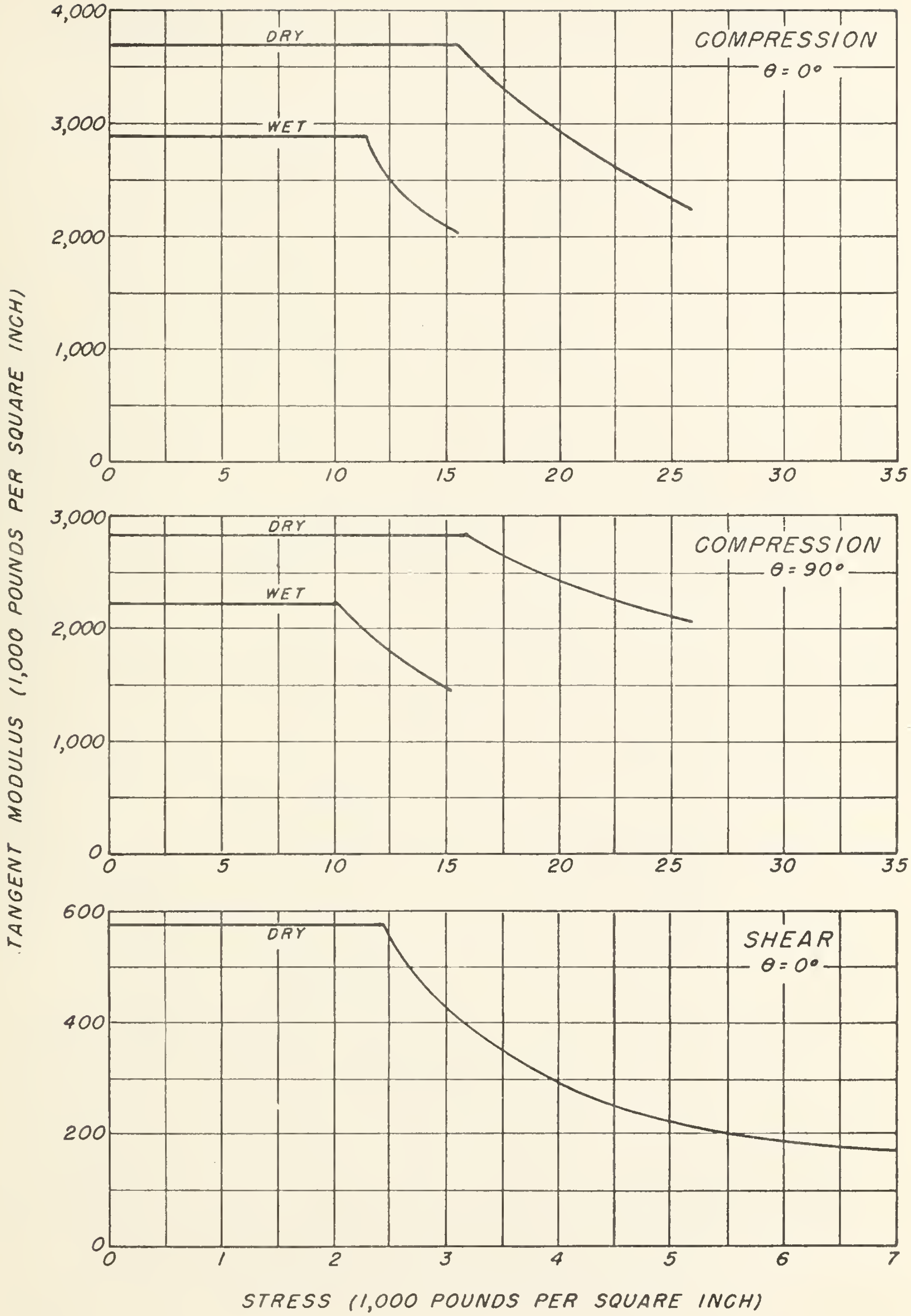
Z M 85375 F

Figure 24. --Relationship between tangent modulus and stress in compression or shear, for laminate made of 112-114 glass fabric and resin 2. Based on curves of figure 10.



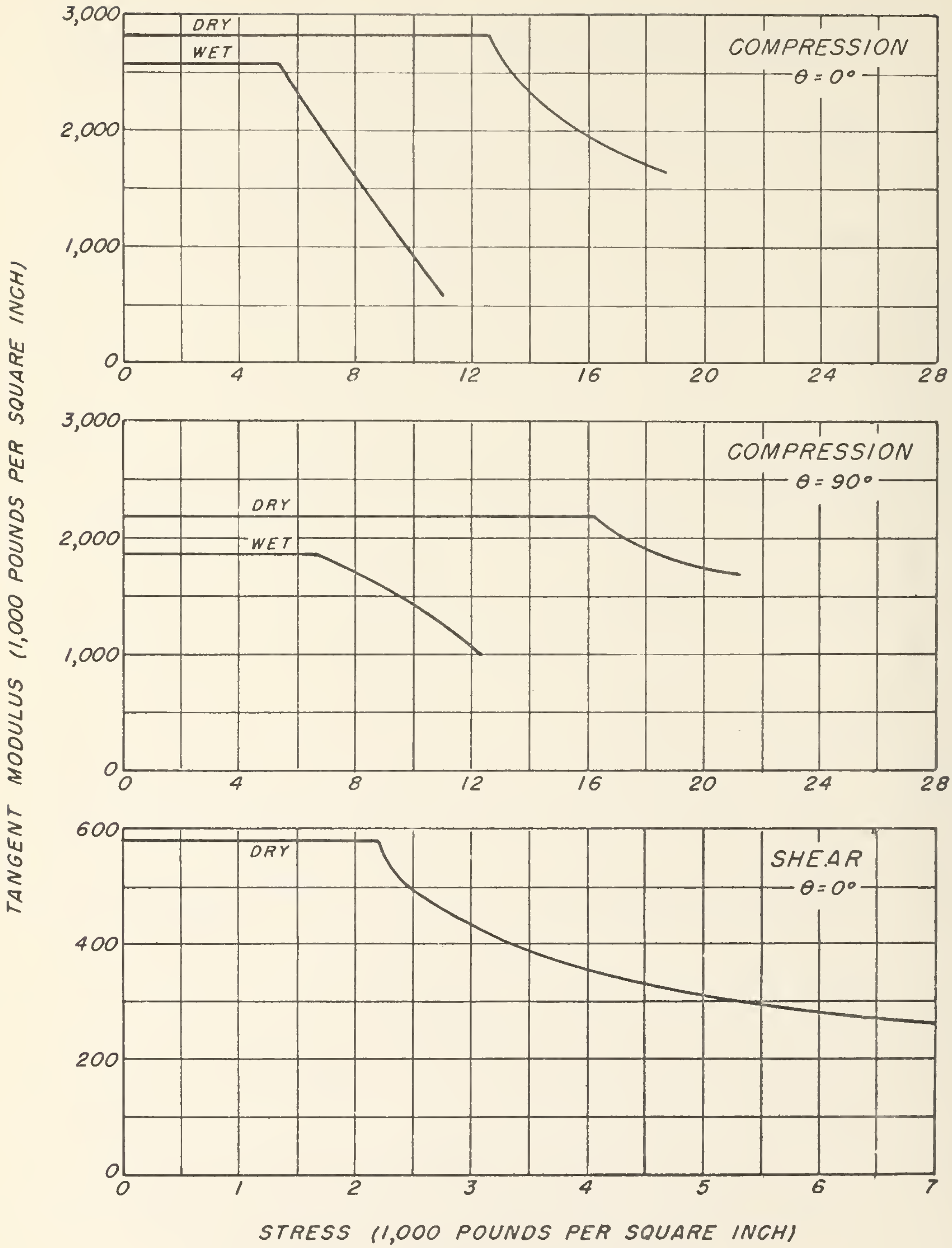
Z M 85376 F

Figure 25.--Relationship between tangent modulus and stress in compression or shear, for laminate made of 116-114 glass fabric and resin 2. Based on curves of figure 11.



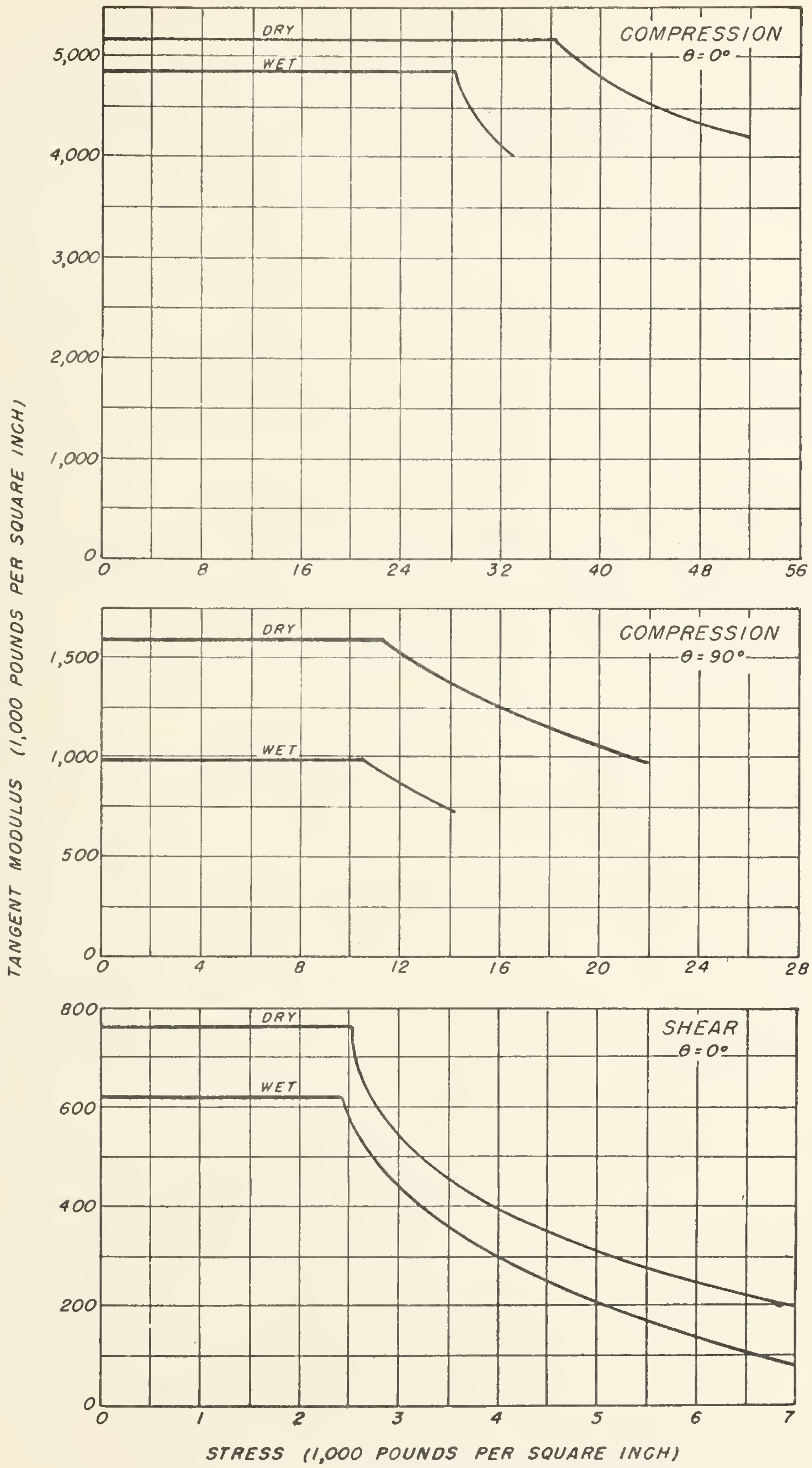
Z M 85377 F

Figure 26. --Relationship between tangent modulus and stress in compression or shear for laminate made of 128-114 glass fabric and resin 2. Based on curves of figure 12.



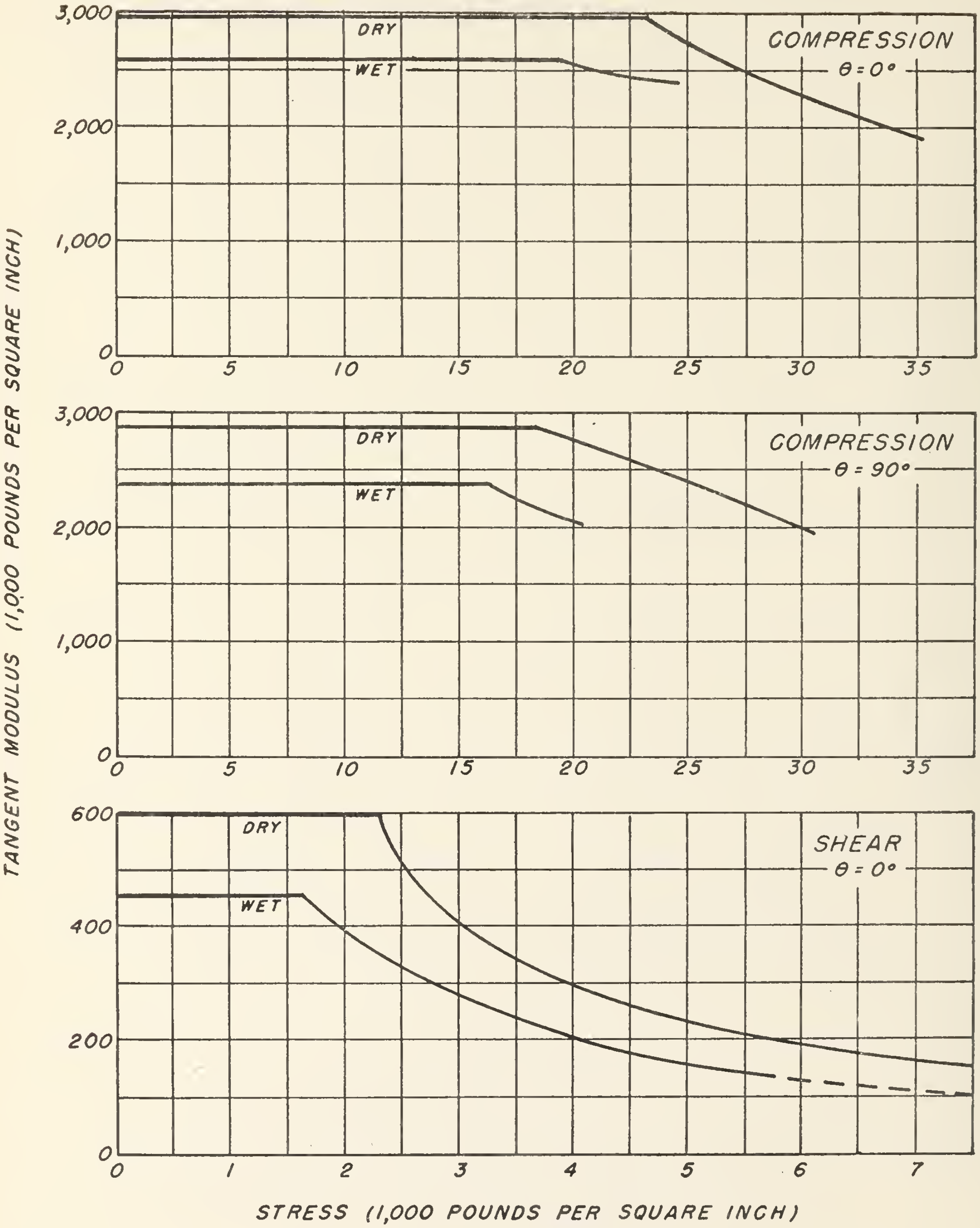
Z M 85378 F

Figure 27. --Relationship between tangent modulus and stress in compression or shear, for laminate made of 162-114 glass fabric and resin 2. Based on curves of figure 13.



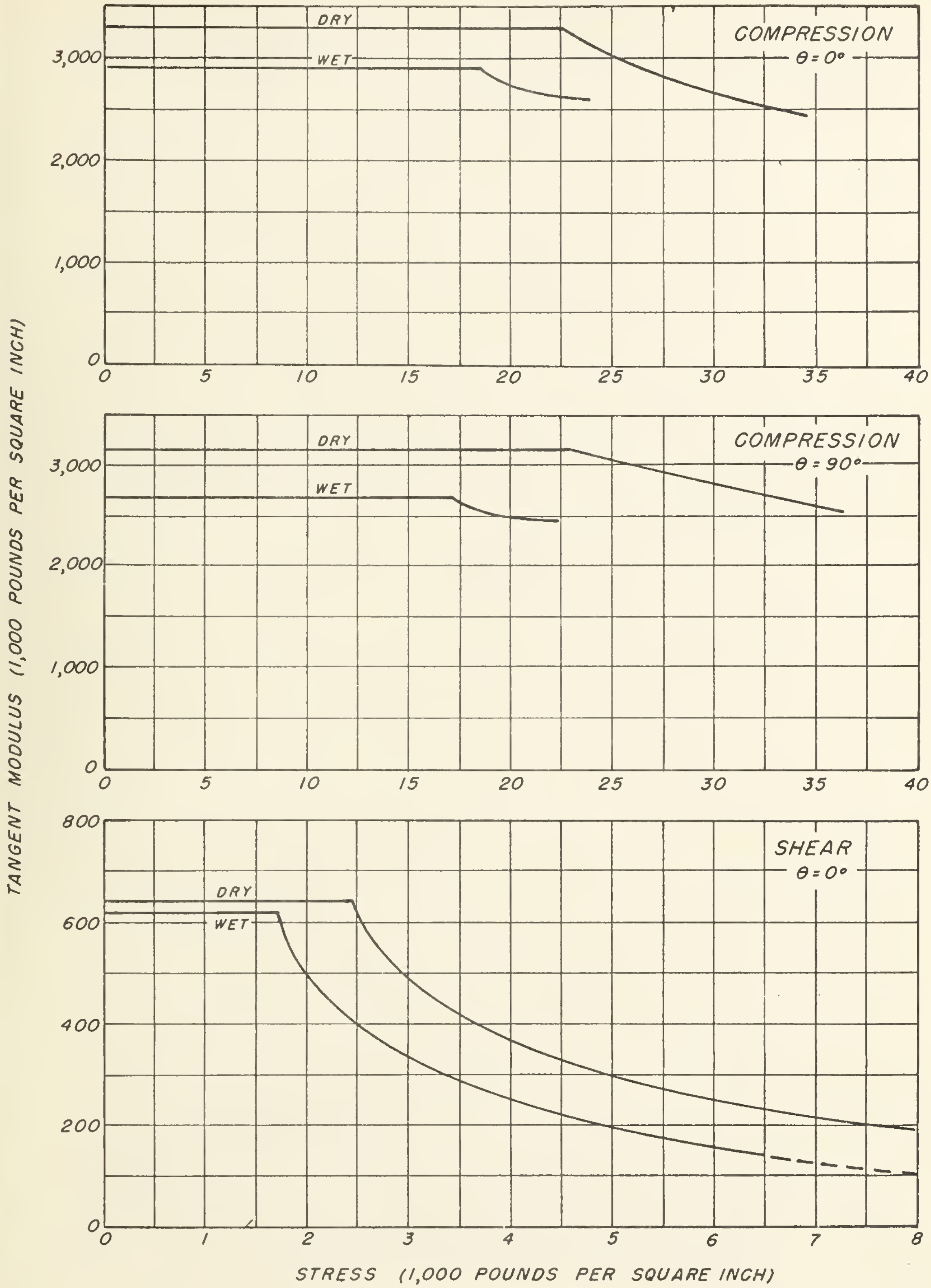
Z M 85379 F

Figure 28. --Relationship between tangent modulus and stress in compression or shear, for laminate made of 143-114 glass fabric and resin 2. Based on curves of figure 14.



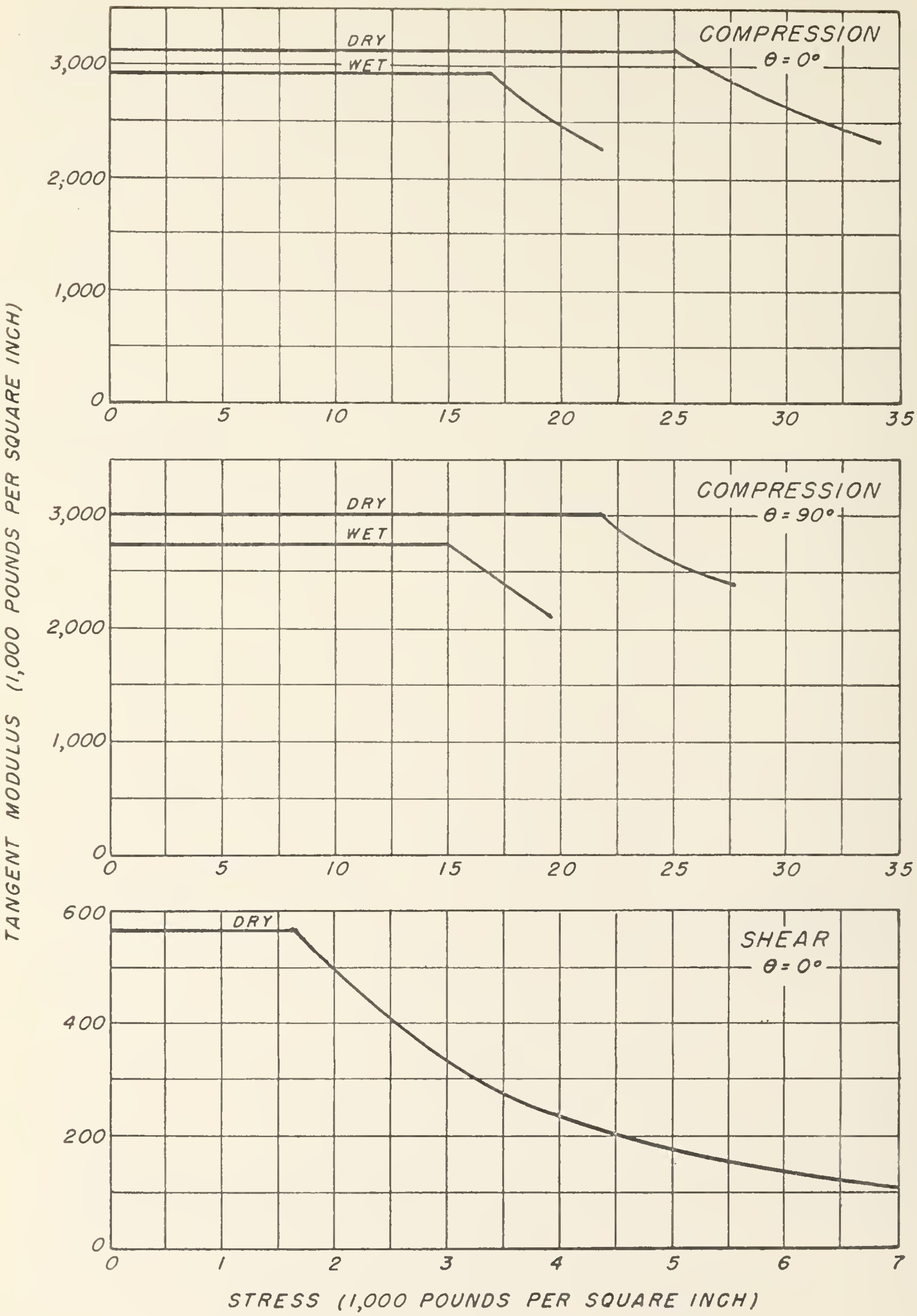
Z M 85380 F

Figure 29. --Relationship between tangent modulus and stress in compression or shear, for laminate made of 120-114 glass fabric and resin 2. Based on curves of figure 15.



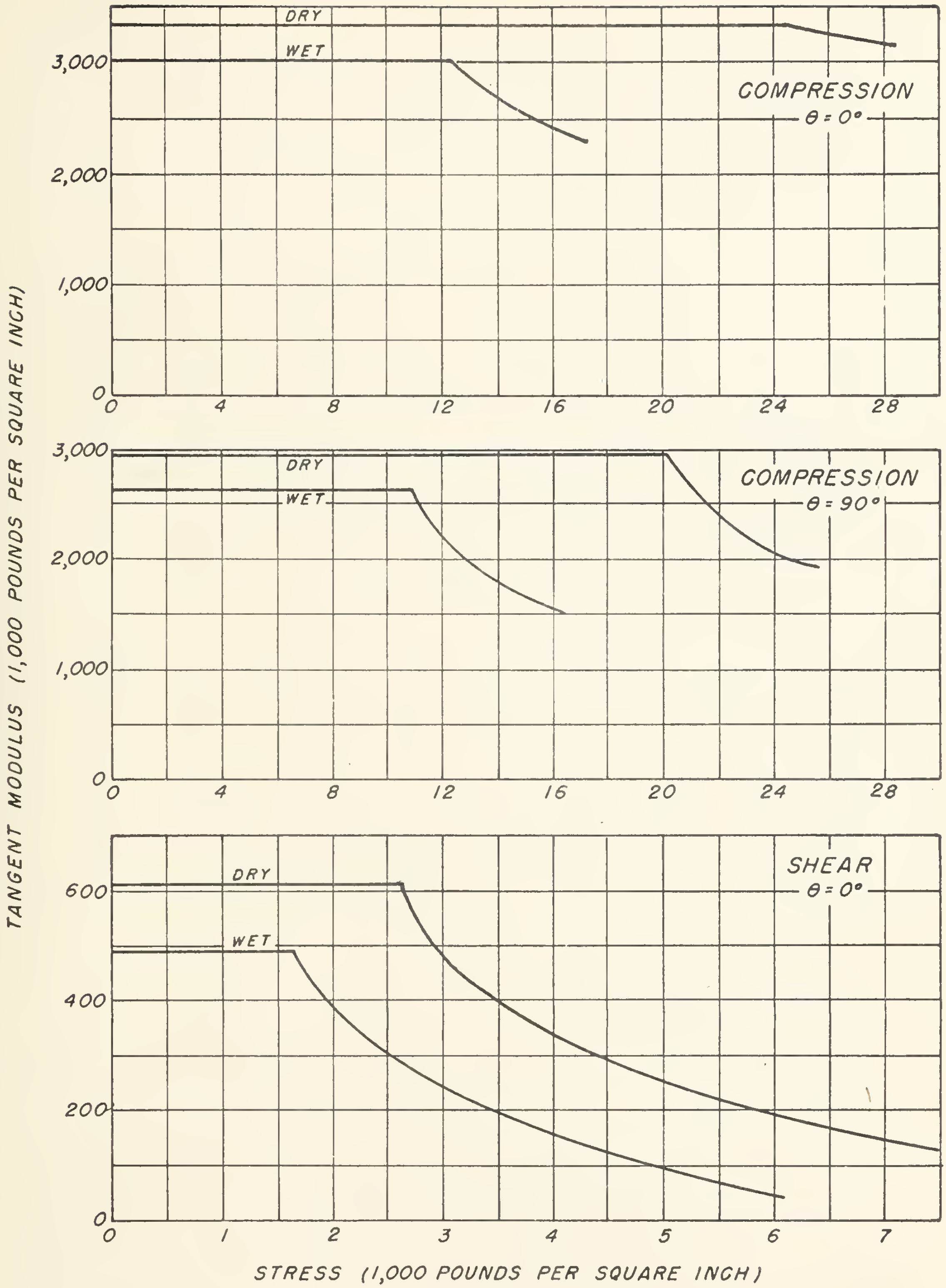
Z M 85381 F

Figure 30. --Relationship between tangent modulus and stress in compression or shear, for laminate made of 181-114 glass fabric and resin 2. Based on curves of figure 16.



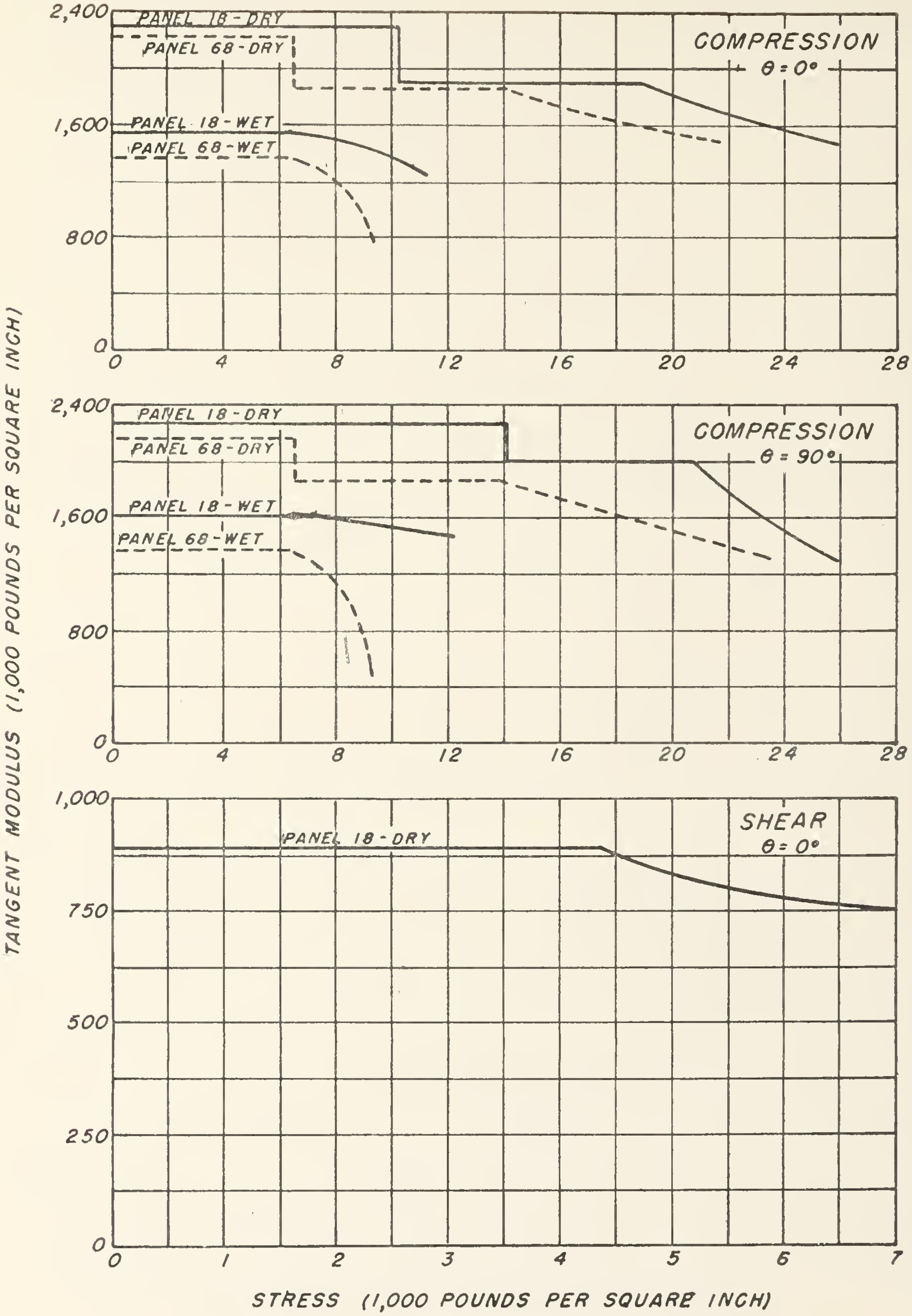
Z M 85382 F

Figure 31. --Relationship between tangent modulus and stress in compression or shear, for laminate made of 182-114 glass fabric and resin 2. Based on curves of figure 17.



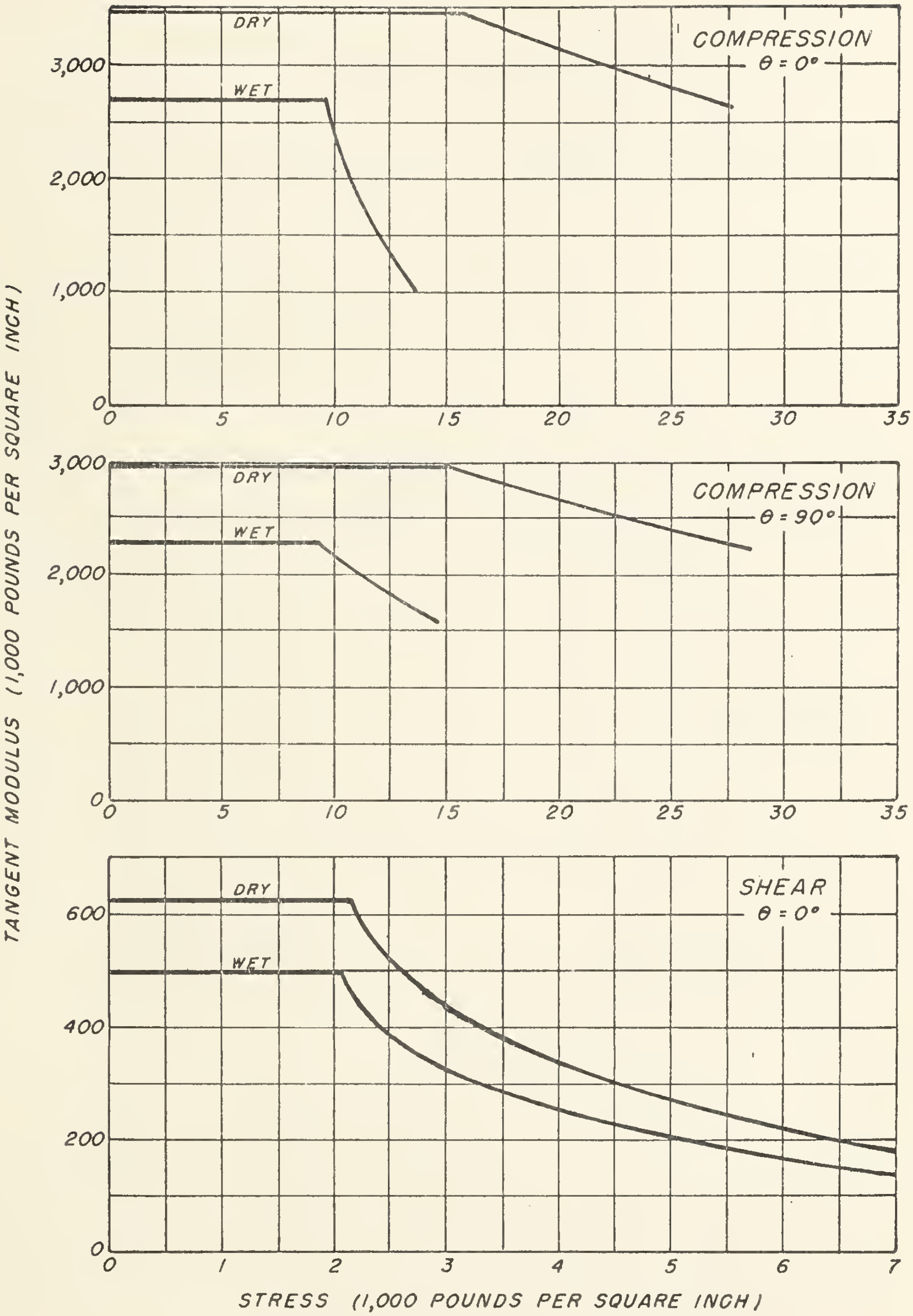
Z M 85383 F

Figure 32. --Relationship between tangent modulus and stress in compression or shear, for laminate made of 184-114 glass fabric and resin 2. Based on curves of figure 18.



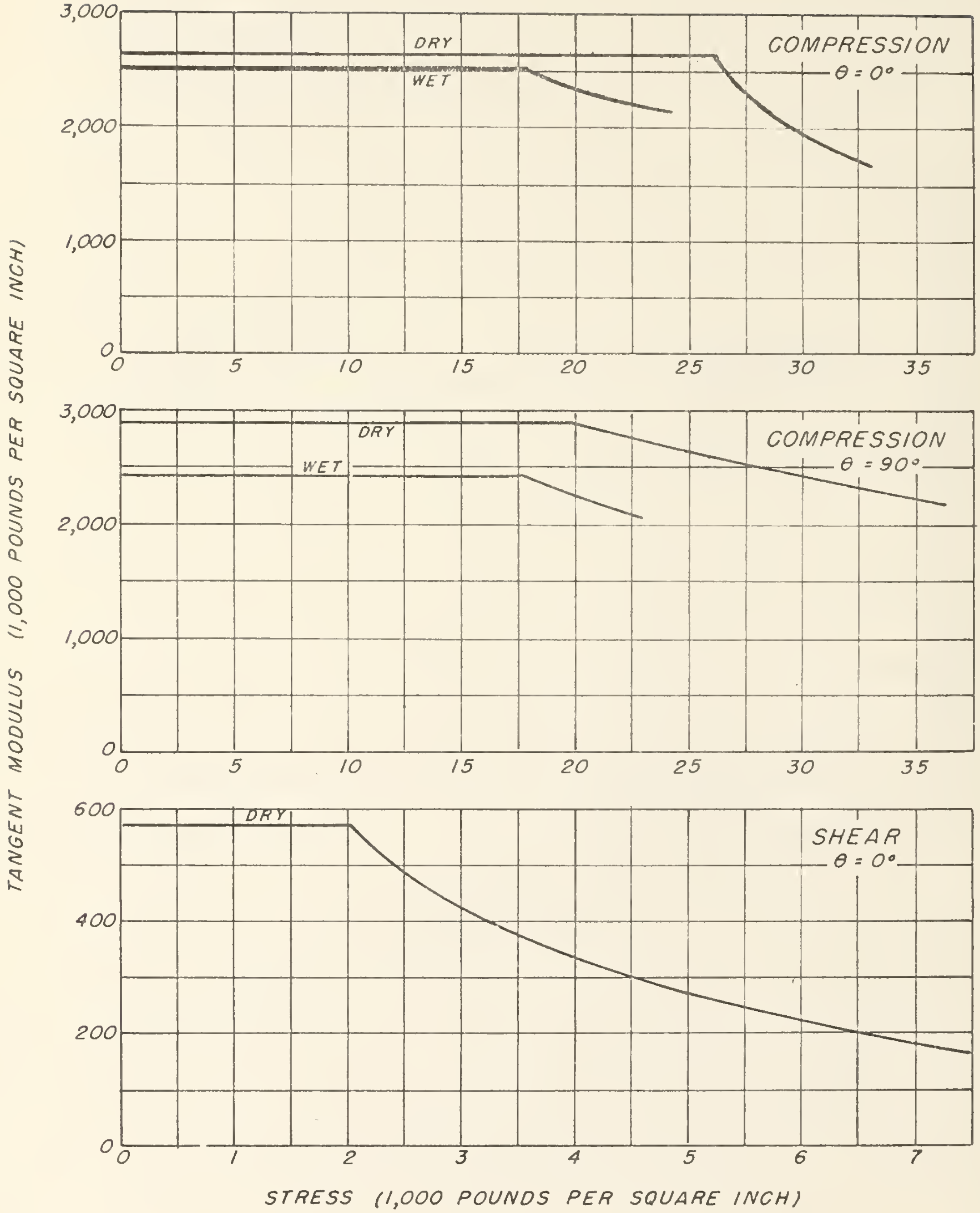
Z M 85384 F

Figure 33. --Relationship between tangent modulus and stress in compression or shear, for laminate made of M-503 glass-fiber mat and resin 2. Based on curves of figure 19.



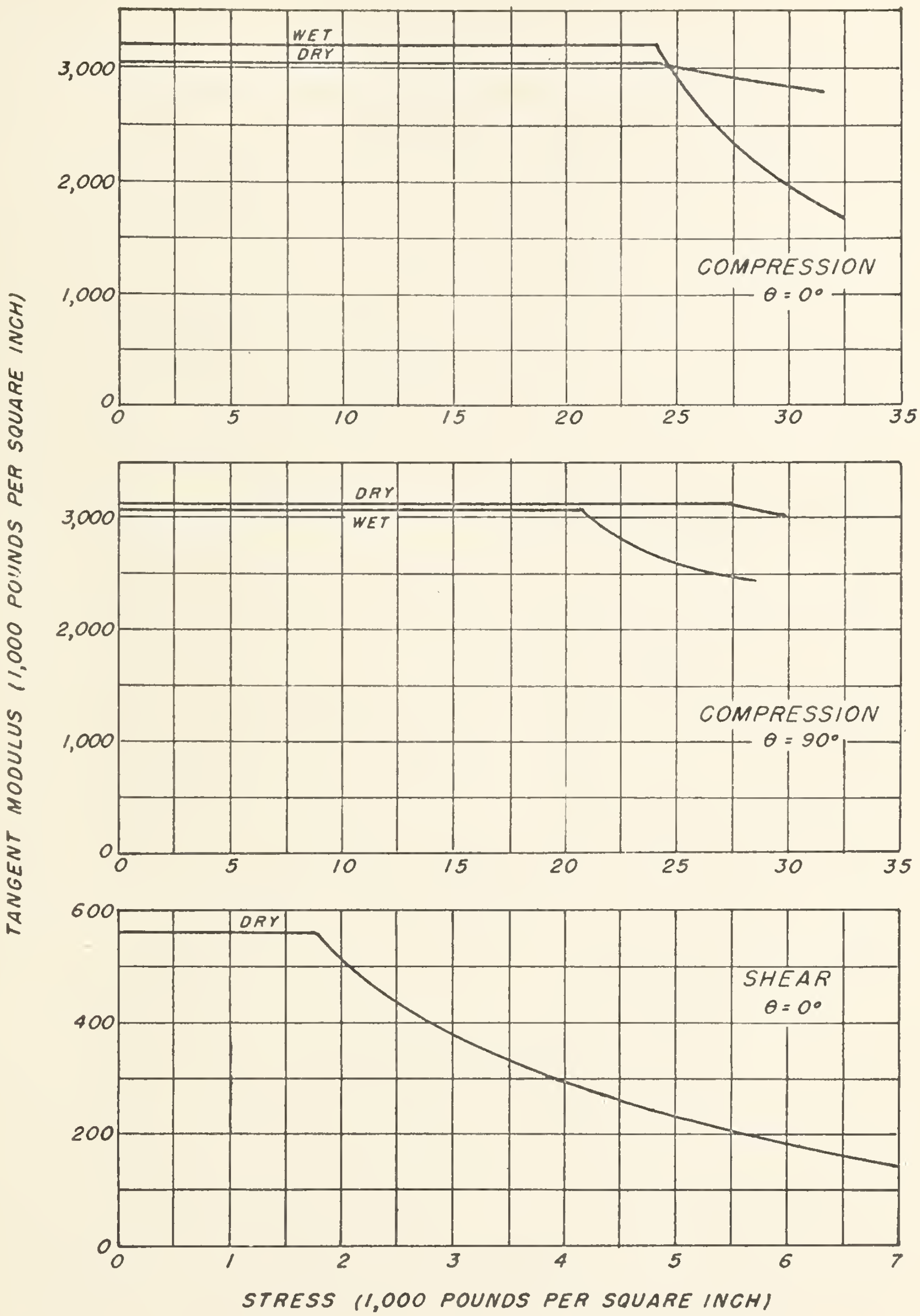
Z M 85385 F

Figure 34. --Relationship between tangent modulus and stress in compression or shear, for laminate made of 128-114 glass fabric and resin 2. Based on curves of figure 20. (The 128-114 fabric represented by this figure was made by a different manufacturer than was that for which results are given in figure 26.)



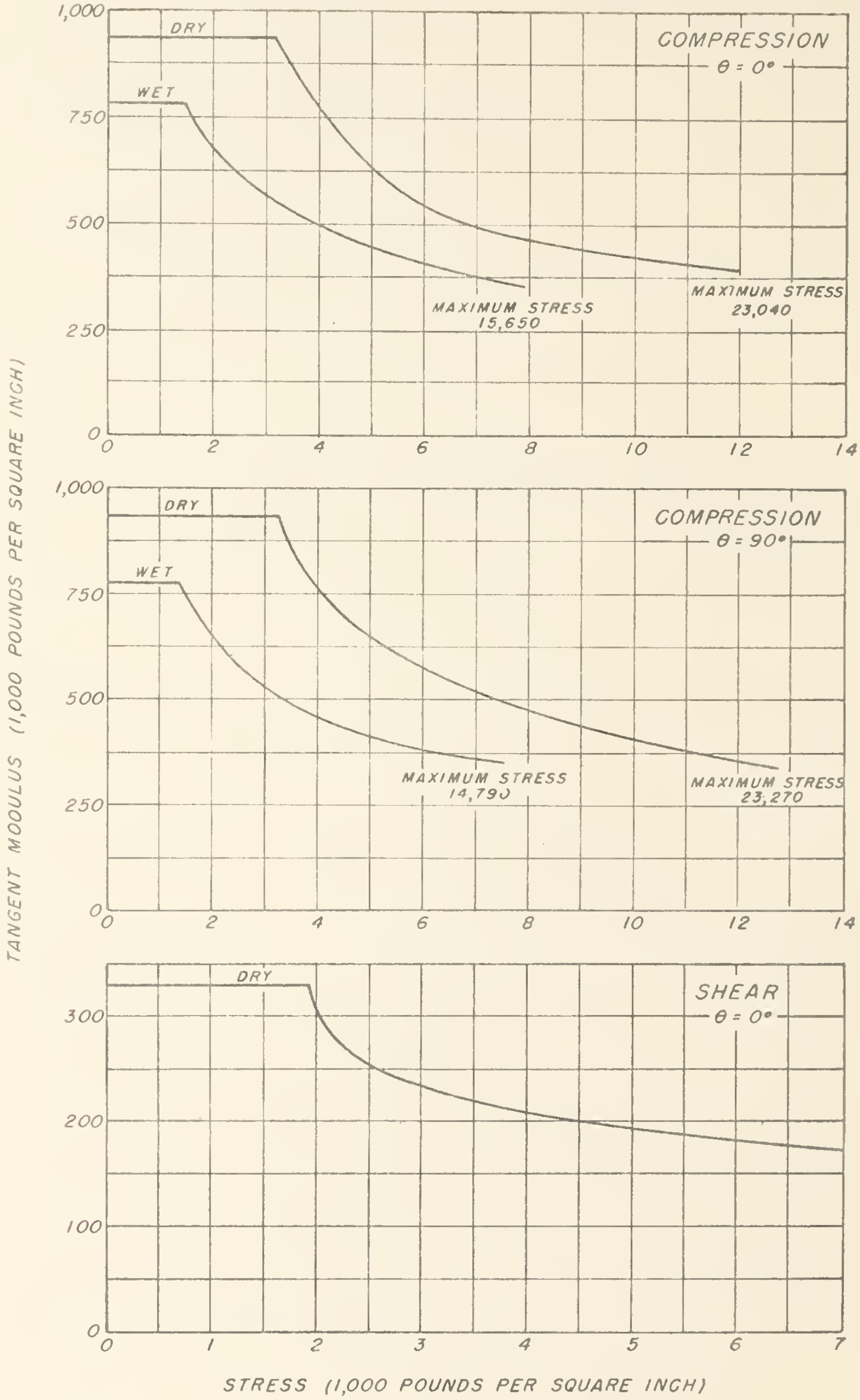
Z M 85386 F

Figure 35. --Relationship between tangent modulus and stress in compression or shear, for laminate made of 181-114 glass fabric and resin 1. Based on curves of figure 21.



Z M 85387 F

Figure 36. --Relationship between tangent modulus and stress in compression or shear, for laminate made of 181-114 glass fabric and resin 9. Based on curves of figure 22.



Z M 85388 F

Figure 37. --Relationship between tangent modulus and stress in compression or shear, for laminate made of cotton fabric and phenolic resin. Based on curves of figure 23.